Sunrise, Sunset, and Fertility

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Abstract

We exploit a series of time zone reforms that involved fifteen provinces across Russia from 2010 to 2016 to estimate the effect of sunrise and sunset times on fertility. We use monthly province-level births data from 2006 to 2018. The reforms moved borders between time zones. Some of the reforms shifted the sunrise and sunset times in the treated provinces down, while other reforms shifted them up. We consider, as explanatory variables, sunrise and sunset times and proportion of days with daylight at a particular hour of evening or morning. In addition, we utilize difference-in-differences estimator, synthetic control method, and a trigonometric model of seasonal fertility. Finally, we address volatility of births as a function of sunrise and sunset times. We find that darkness in the evening and, to a lesser extent, darkness in the morning are associated with an increase of at least one percent in fertility. We also find that not only the level but also seasonal volatility of births is sensitive to sunrise and sunset times.

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1 Introduction

In this paper, we estimate the effect of sunrise and sunset times on fertility. This effect is interesting for three reasons. First, fertility is an important variable. Indeed, we find large effects of several percentage points that relate daylight to births. Second, the effect of daylight on fertility is an example of sensitivity of behavioral and strategic outcomes to the environment. Such evidence is particularly relevant in the epoch of growing awareness of the effect of environmental changes. Third, time institutions (time zones and daylight saving time) remain viable in many countries and their efficiency remains uncertain. For instance, recently, the European Union decided, following an opinion poll, to abolish daylight saving time transitions and to adopt a permanent annual time from 2021 onward[1]. Thus, effects of time institutions are in focus of ongoing political processes.

We use arguably the best empirical setup to investigate the effect of daylight on human behavior: Russia, the biggest time laboratory in the world. Russia differs from any other country by the very long distance between its eastern and western ends. The longitudinal difference between the westernmost province, Kaliningrad Oblast, and the easternmost province, Chukotka, is 157°, which corresponds to 11 natural (nautical) time zones. Russia differs from other countries also by its relatively frequent time zone reforms. The introduction of the time zones in 1919 was followed by a long list of changes that continue to this day.

An example of a series of reforms that corrected each other is the 2010-2016 period. Despite its constitutional definition as a federation, Russia is a centralized country. In par-

[1] https://www.theguardian.com/world/2019/mar/26/european-parliament-votes-to-scrap-daylight-saving-time-from-2021

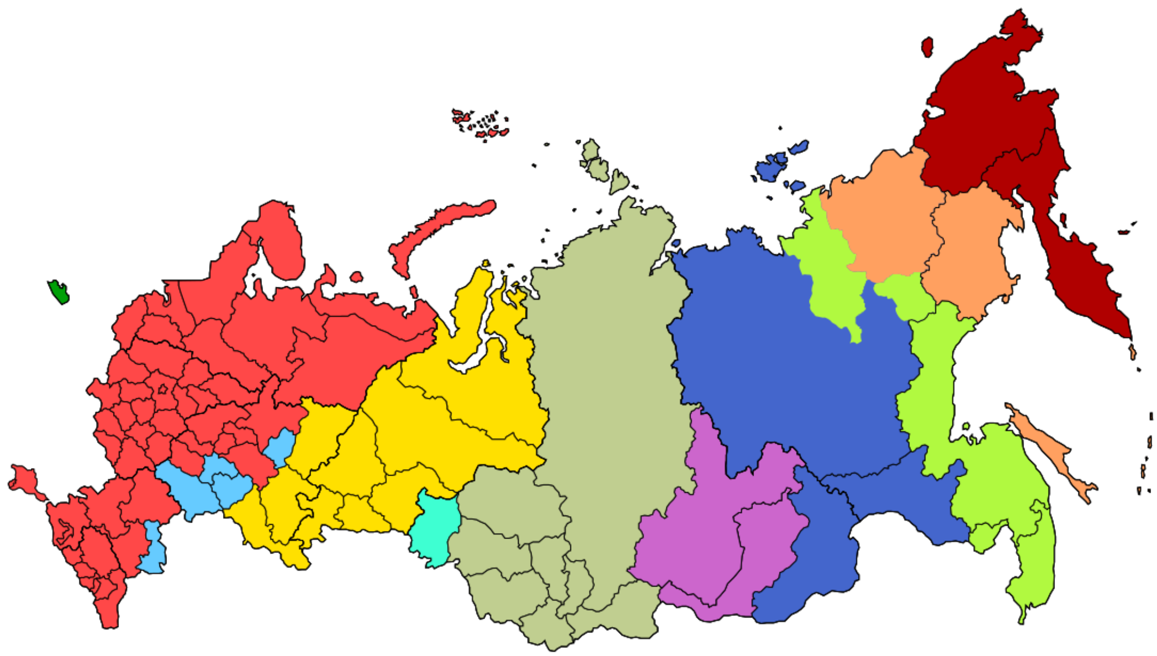
ticular, at any point in time, about 50 out of the total[2] of 85 provinces use Moscow Time. The Russian president stated in his annual address to the parliament in 2009 that distant regions should be set "closer" to Moscow, which should improve the coordination between the local governments and the central one. In the following year, the number of provinces in the Moscow Time Zone increased from 50 to 52 and increased further to 54 in 2014. However, the implementation of the 2010 reform was unpopular. The reform was recognized as a failure already in 2011 and a new reform was initiated. Later, a 2014 reform revised the one of 2011. In turn, a 2016 reform attempted to correct the one of 2014. The map in Figure 1 shows the Russian time zones following the reform of 2016, which is the last reform that is integrated in the data of this paper.

The monthly birth data that we use covers the period from 2006 to 2018. During this period, several time zone reforms took place. These reforms are summarized in Table 1. In March 2010, the time zone in five regions was shifted one hour downward. In March 2011, DST transitions stopped and all Russia moved one time zone up. In October 2014, all Russia except of the five regions that were treated in 2010, shifted one time zone downward. Two regions shifted two time zones downward. Finally, in different months of 2016, the time zone in ten regions shifted upward, including the two regions that shifted two time zones downward in 2014.

We use several modelling strategies to estimate the impacts of exogenous changes in time of sunrise and sunset on fertility. First, we use regional-month and region-year fixed effects as well as allowing for the first-order autoregressive process (AR1) to control for deterministic and cyclical changes in fertility without the reforms. Further, as a robustness check, we

[2]Including Crimea and Sevastopol, which were annexed in 2014.

Figure 1: Time zones in Russia as of 2018



Time zones from west to east: KALT Kaliningrad Time UTC+2 (MSK-1), MSK Moscow Time UTC+3 (MSK+0), SAMT Samara Time UTC+4 (MSK+1), YEKT Yekaterinburg Time UTC+5 (MSK+2), OMST Omsk Time UTC+6 (MSK+3), KRAT Krasnoyarsk Time UTC+7 (MSK+4), IRKT Irkutsk Time UTC+8 (MSK+5), YAKT Yakutsk Time UTC+9 (MSK+6), VLAT Vladivostok Time UTC+10 (MSK+7), MAGT Magadan Time UTC+11 (MSK+8), PETT Kamchatka Time UTC+12 (MSK+9).

Table 1: Time zone reforms in Russia from 2010 to 2016

Date	Affected provinces	Direction (if any time zones changed)	Remarks
March 28, 2010	5 provinces	$\downarrow$	
August 31, 2011	All	$\uparrow$	Elimination of DST
March 30, 2014	Crimea, Sevastopol[(3)]	$\Uparrow$	
October 26, 2014	80 provinces	$\downarrow$ (78 provinces) $\Downarrow$ (2 provinces)	
March 27 to December 4, 2016	10 provinces	$\uparrow$	

Notes: (1) $\uparrow$ and $\downarrow$ correspond to a shift of one time zone, $\Uparrow$ and $\Downarrow$ correspond to a shift of two time zones.

(2) The number of affected provinces is given in accordance with the administrative division of Russia in 2018.

(3) Crimea was annexed by Russia a few days earlier, but the annexation did not achieve international recognition.

adopt the trigonometric regression model commonly used in the literature on fertility to model the counterfactual movements in births without the time zone reforms. Exploiting the time zone reforms in Russia, we also employ difference-in-differences model to construct the counterfactual and estimate the effects on sunrise and sunset times on both level and volatility of numbers of births. Further, different weights for each control region are implemented by applying the synthetic control methods.

Our results show that the more sunlight in the later hours in the evening (or the reform that made sunset later) negatively affects the numbers of births. Such finding is robust to all three model specifications. However, the effects of later sunrise in the morning (or the less sunlight in the early hours in the morning) are rather inconclusive. While the Dif-in-Difs model demonstrates some positive effects on fertility, the results from the trigonometric regression are weakly significant (at 10% level) in the opposite direction.

The paper is organized as follows. In Section 2, we explore related literature. We then outline our data and methodology in Section 3, while results are presented and discussed in Section 4. Concluding remarks are in Section 5.

2 Literature Review

A few studies explore seasonality patterns in births and such patterns (albeit differences in the peaks and troughs across months) were observed around the world in both developed and developing countries (Becker, 1981; Miron et al., 1994; Fellman, 2019). Level of sunshine or intensity of environmental light is one of the factors that could contribute to seasonal patterns of fertility[3]. For instance, James (1990) showed that seasonal fertility in the US and Europe correlates positively with latitude hinting an importance of luminosity, whereas Cummings (2010) used monthly birth data from seven countries to demonstrate that increases in environmental light intensity were highly correlated with birth seasonality.

One of the main underlying mechanisms linking intensity of sunlight with movement in numbers of monthly births is vitamin D absorption. One systematic review (Irani and Merhi, 2014) also found evidence in supporting of the role of vitamin D on ovarian physiology, while Conway and Trudeau (2019) showed that sunshine increases fertility differently between non-Hispanic black and Caucasian white in the US and such effects could be explained by inhibition of vitamin D production due to skin pigmentation. Such an interaction between level of sunshine exposure and skin pigmentation seems to explain racial disparity in birth weight in the US (Trudeau et al., 2016). However, a systematic review by Beltran et al. (2014) suggested that only limited number of studies explored an association between sunshine exposure and adverse pregnancy outcomes such as low birth weight. In addition, beyond fertility health, low level of sunshine / UV-light exposure could be related to health problems in adults like Multiple Sclerosis, which leads to symptoms e.g. tremble, pain, fatigue, or bowel trouble (Balbuena et al., 2016; Verheul et al., 2013).

[3]Other factors discussed in the literature are such as temperature (Miron et al., 1994) and a delay of rainy season (Sellers and Gray, 2019).

3 Data and Methodology

3.1 Data

Our data comes from Institute of Demography of Higher School of Economics (IDEM). The institute publishes monthly demographic province-level data on its online outlet "Demoscope Weekly". We use all available data consisting of monthly births from 2006 to 2018 in all 85 (83 before annexation of Crimea in 2014) provinces. Thus, we exclude data from Crimea.

3.2 Models

Sunrise and sunset times

We depart from a model where the average sunrise and sunset times in the month of conception are considered as the main explanatory variables. The model is

$$Births_{iym} = \beta_1 Sunrise^9_{iym} + \beta_2 Sunset^9_{iym} + \beta_3 Marr^{10-24}_{iym} + \gamma_{im} + \delta_{iy} + \varepsilon_{iym} \tag{1}$$

where $Births_{iym}$ is the outcome variable that accounts for fertility. We consider two outcome variables. The first outcome is the natural logarithm of the number of births in region i, in year y, and month m. This variable allows for interpretation of the coefficients as percentage of change in fertility. The second outcome is the number of births per 1,000 of population. The latter outcome fits better than the former one models such as synthetic control, where the size of population in the control area should not affect the the fit between the treated and control regions. The main variables of interest $Sunrise^9$ and $Sunset^9$ account for the average sunrise and sunset times in the month that is nine months before the birth.

The variable $Marr^{10-24}$ controls for the number of marriages from 24 to 10 months before the birth, because propensity to marry may be affected by the sunrise and sunset times, generating a bias if omitted from the model. γ_{im} is a region-specific seasonal effect of the month and δ_{iy} is the region-year fixed effect. The disturbance ε is allowed to follow within-region autoregression (using Stata function *xtregar*).

In order to estimate the effect of the sunrise and sunset times interacted with rate of marriage, we proceed with estimating a model with interaction terms:

$$\begin{aligned} Births_{iym} = \beta_1 Sunrise_{iym}^9 + \beta_2 Sunset_{iym}^9 + \beta_3 Marr_{iym}^{10-24} + \beta_4 Marr_{iym} \times Sunrise_{iym}^9 \\ + \beta_5 Marr_{iym} \times Sunset_{iym}^9 + \gamma_{im} + \delta_{iy} + \varepsilon_{iym} \end{aligned} \tag{2}$$

Seasonal volatility of births

There may exist two separate effects of sunrise and sunset times on fertility. The first effect is on the level of fertility. This effect is considered in Equation (1). The second possible effect is on seasonality of births. Conditional on the overall yearly level of fertility, individuals may spread births differently over the year as a result of a time zone reform. We address this possibility by estimation of the following model:

$$volBirths_{iym} = \beta_1 Sunrise_{iym}^{9ma} + \beta_2 Sunset_{iym}^{9ma} + \beta_3 volMarr_{iym}^{10-24} + \gamma_{im} + \delta_{iy} + \varepsilon_{iym} \tag{3}$$

where $volBirths_{iym}$ is the logarithm of the standard deviation of the births in region i

over 12 months around month m of year y. The variables $Sunrise^{9ma}$ and $Sunset^{9ma}$ account for the moving average sunrise and sunset times around the month of conception (the average is over 12 months). The variable $volMarr^{10-24}$ is the logarithm of the standard deviation of the average number of marriages. The standard deviation is of 12 averages of overlapping time windows, where each time window is 14 months long, and the last time window is from 24 to 11 months before the birth. The region-year and the region-month effects follow their definition in Equation (1).

Proportion of days with daylight at a particular hour

In the next step of the analysis, we attempt to identify the specific hours when daylight is important. In particular, we consider the proportion of days with daylight at a particular hour (7am, 8am, and 9am for the morning and 5pm, 6pm, 7pm, 8pm, and 9pm for the evening). The model is

$$Births_{iym} = \alpha D(t,h)_{ijt} + \gamma_{im} + \delta_{iy} + \varepsilon_{iym} \tag{4}$$

where the variable $D(t,h)$ is the proportion of days with darkness (for $t =$ 7am, 8am, or 9am) and light (for $t =$ 5pm, 6pm, 7pm, 8pm, or 9pm) during the month of conception.

Trigonometric model of seasonal fertility

As a series of numbers of births per month tends to demonstrate its own cycle and seasonality, many studies (such as Becker, 1981; Fellman, 2019) use the Fourier analysis based on sums of trigonometric functions to model movements in the numbers of births. As a robustness check, we follow literature in this area (Fellman, 2019, e.g.) and adopt the multiple trigonometric regression:

$$Births_{iym} = \alpha + \sum_{n=1}^{N} (\theta_n sin(2n\pi t_{ym}) + \gamma_n cos(2n\pi t_{ym})) + \varepsilon_{iym} \quad (5)$$

where sin(.) and cos(.) are sine and cosine function respectively while t_{ym} represents a variable in a [0,1] interval transformed from the number of months in our data such that t in the first period is equal to 0 and the last period is equal to 1. N is the number of pairs of trigonometric terms included in the model. To account for potential trend in our birth data, we modify such a model by adding linear and quadratic trend (polynomial-trigonometric regression (Eubank and Speckman, 1990) as well as the number of marriages from 24 to 10 months before the birth, $Marr^{10-24}$. Standard errors (ε_{iym}) are clustered at regional level.

Further, we hypothesize that the impacts of changes in sunrise and sunset time can be modelled as deviations from such trends and cycles by adding sunrise/sunset time ($Sunrise^9$ and $Sunset^9$) or the proportion of days with darkness and light ($D(t, h)$) defined earlier as follows:

$$\begin{aligned} Births_{iym} = \alpha + \beta_1 Sunrise^9_{iym} + \beta_2 Sunset^9_{iym} + \beta_3 Marr^{10-24}_{iym} \\ + \sum_{n=1}^{N} (\theta_n sin(2n\pi t_{ym}) + \gamma_n cos(2n\pi t_{ym})) + \delta_1 trend + \delta_2 trend^2 + \varepsilon_{iym} \end{aligned} \quad (6)$$

$$Births_{iym} = \alpha + \beta_t D(t,h)_{ijt} + \lambda Marr_{iym}^{10-24} + \sum_{n=1}^{N} (\theta_n sin(2n\pi t_{ym}) + \gamma_n cos(2n\pi t_{ym}))$$
$$+ \delta_1 trend + \delta_2 trend^2 + \varepsilon_{iym} \quad (7)$$

Yet to determine the exact number of pairs and order of the trigonometric terms to be included in the model, forward selection process with stepwise regression is implemented. The models are estimated as generalized linear model (GLM) with Poisson distribution and logarithmic link function using Stata function stepwise: glm (Cox, 2006).

Difference in differences model

We proceed now with a more straightforward strategy to identify the effect of the time zone reforms. We introduce a difference-in-differences estimator in this section (Bertrand et al., 2004) and then the synthetic control estimator in the following section.

In the first step, we find the set of control regions for each of the treated ones. The control regions should satisfy two conditions: (i) similar to the treated region sunrise and sunset times in the pre-reform period and (ii) dissimilar to the treated region sunrise and sunset times during the reform period.

For the five regions that were treated in 2010, the reform period is April 2010 to October 2014. For Chita and Magadan, which experienced a two-hour shift in October 2014, the reform period is November 2014 to March and April 2016, respectfully. For the eight regions where the time zone changed in 2016 (excluding Chita and Magadan), the reform period starts with the reform and lasts until the end of our data.

We find the control regions using a root of mean sum of squares criterion. For each pair of regions i, j, we define the root mean sum of squares for the reform period

$$RMS^{r}_{ij} = (\frac{1}{||RP||}\sum_{t\in RP}((sunrise_{it} - sunrise_{jt})^2 + (sunset_{it} - sunset_{jt})^2))^{\frac{1}{2}}.$$

where RP is the list of reform months. Similarly, we define the root mean sum of squares for the pre-reform period:

$$RMS^{nr}_{ij} = (\frac{1}{||PRP||}\sum_{t\in PRP}((sunrise_{it} - sunrise_{jt})^2 + (sunset_{it} - sunset_{jt})^2))^{\frac{1}{2}},$$

where PRP is the list of pre-reform months. We calculate these terms for pairs of each of the treated regions with each of the other Russian regions. Then we find for each of the treated regions a set of control regions, such that $RMS^{nr} < 0.5$ and $RMS^{nr} > 0.75$. This criterion helps to find control regions for 11 out of 15 regions affected by reforms during the 2010-2016 period. The results are not principally different for other thresholds, even though the choice of control regions for each of the treated ones would be different.

Each treated region has a different number of control ones. It ranges between one control region for Chukotka and 24 control regions for Samara. We plot several examples. Figure 2 shows the mean sunrise time in Udmirtia, one of the five regions affected by 2010 reform, versus mean sunrise time in the control regions of Udmurtia. One can see that until March 2010 and after October 2014 the sunrise times in Udmurtia and the control regions are very similar. Within the March 2010 to October 2014 period, one can distinguish between the period before and after March 2011, when Russia abandoned DST transitions and shifted one time zone up. Figure 3 shows the example of Astrakhan, where the reform took place in March 2016.

Thus, for the five regions that experienced the reform of March 2010 and for the two regions that experienced the two-hour-shift in October 2014, the time zone (and sunrise and sunset times) during the reform period are lower than in control regions. For the eight regions that experienced the reform of 2016 (but not the reform of 2014), the time zone (and sunrise and sunset times) during the reform period are higher than in the control regions.

After finding the set of control regions for each of the treated ones, we estimate, for each of the treated regions, the following difference-in-differences model:

$$FR_{iym} = T_i \times R_{ym}\beta + \gamma(n)_{im} + \delta_{iy} + \varepsilon_{it} \tag{8}$$

where FR_{iym} is the total fertility rate (births per 1,000 of population) in region i, in year y, and month m. The variable T_i is one if region i is the treated region and zero if it is a control region, R_{ym} is one if the month nine months before month m in year y was in the range of reform months (for example, for Udmurtia the range of reform months is April 2010 to October 2014) and zero otherwise. $\gamma(n)_{im}$ is the region-specific polynomial trend of degree n and δ_{iy} is a region-specific seasonal effect of the month. The reasons that we control for region-specific polynomial trend and not for regional-specific year fixed effects is that for some of the reforms, the treatment interaction variable $T_i \times R_{ym}$ is fully correlated with calendar years. The disturbance ε is allowed to follow within-region autoregression (using Stata function *xtregar*).

Figure 2: Mean sunrise time in Udmurtia and in its control regions

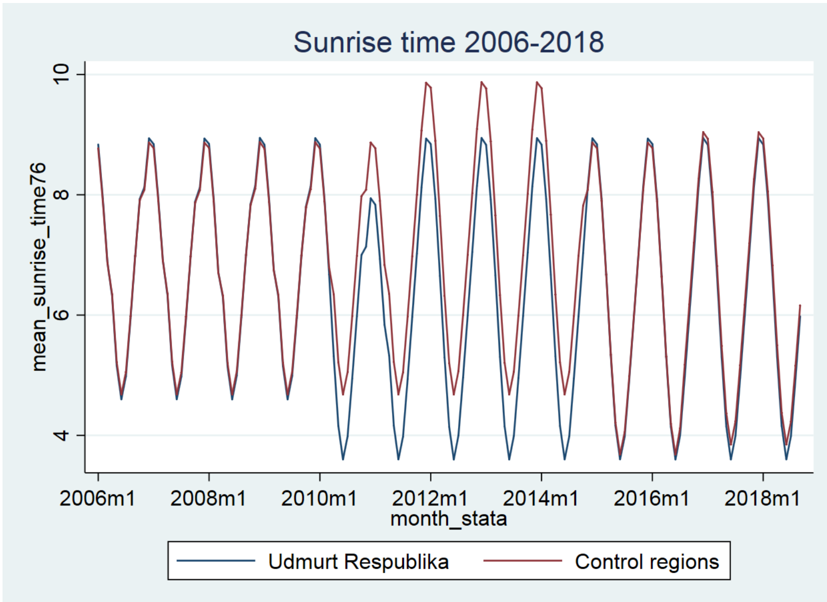
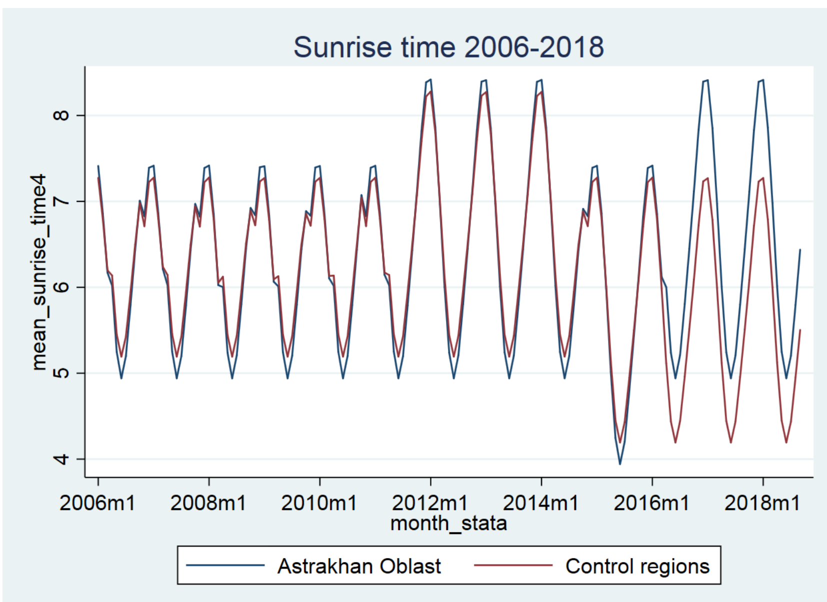


Figure 3: Mean sunrise in Astrakhan and in its control regions



Synthetic control model

An extension to the difference-in-differences strategy is the increasingly popular synthetic control method. In this method, not only that a set of control regions is found, but the control regions are weighted such that their weighted average constitutes a synthetic twin of the treated region in the pre-treatment period. The vector of weights is the synthetic control. Being a synthetic control means similarity to the treated region in terms of socio-economic outcomes that are, put together, a good predictor of the outcome variable. The outcome variable in the pre-treatment period, predicted by the socio-economic regressors, should be similar in the synthteic control and in the treated regions. The estimator of the effect of the treatment is the average difference in the outcome during the treatment period minus the average difference in the outcome in the pre-treatment period.

Our implementation of the synthetic control strategy slightly differs from the seminal papers (Abadie and Gardeazabal, 2003; Abadie et al., 2015). In is previous literature the data is annual, and the pre-treatment period was divided into two parts - training period, used to find weights, and validation period, used to confirm the predictive power of the weights to fit the outcome variable in the synthetic control and in the treated region. In our case, the pre-treatment period is short (2006-2010 for the first set of reforms). However, we have monthly data of the outcome of interest. Thus, we perform the following exercise. We find the vector of weights using the annual socio-economic regional data in the control regions (which are found according to the procedure described in the difference-in-differences section above). But we use the monthly births data in the pre-treatment period as a validation data set.

The algorithm that we implement is the following:

Step 1. Using the stepwise procedure, find a set of annual socio-economic regressors that best predict the annual regional fertility rates.

Step 2. Use the root mean sum of squares criterion to find the set of control regions for each of the treated ones (see the difference-in-differences section above).

Step 3. Use annual data from 1995 on to find a vector of weights for the control regions that minimizes the difference between the monthly births rate in the treated region and the monthly births rate in the synthetic control region during pre-reform period (for instance, it would be the 2006-2010 period for the regions treated in March 2010). The optimization is given a vector of weights put on the regressors, which are found such that the difference in the weighted regressors between the synthetic control region and the treated region is minimized (for details, see Abadie et al., 2010).

Step 4. Do not proceed if the fit of the outcome of interest (monthly rate of births) in the synthetic control and the treated regions during the pre-treatment period is not sufficiently good.

Step 5. Estimate the treatment effect as the average difference in the outcome during the treatment period minus the average difference in the outcome in the pre-treatment period.

4 Results

Sunrise and sunset times interacted with marriages

The results of estimation of Equations (1) and (2) are shown in Table 2. Both the sunrise and the sunset time affect fertility. The net effect of shifting the clock one hour forward is a one-percent decrease in fertility (a sum of the first two coefficients in column 1). The effect

Table 2: Effects of sunrise and sunset times on fertility

VARIABLES	(1) ln(Births)	(2) ln(Births)
$Sunrise^9$	0.0845**	0.0784**
	(0.0331)	(0.0350)
$Sunset^9$	-0.0959***	-0.0353
	(0.0329)	(0.0357)
$Sunrise^9 \times ln(Marr)$		0.00182
		(0.00196)
$Sunset^9 \times ln(Marr)$		-0.00957***
		(0.00221)
$ln(Marr)$	0.168***	0.333***
	(0.0230)	(0.0457)
Observations	10,690	10,690
Number of region_id	85	85

The estimation method is AR(1) with fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

of a postponed sunset comes in interaction with rate of marriages 10 to 24 months before conception (column 2), while the effect of a postponed sunrise is unrelated to marriage.

Seasonal volatility of births

Table 3 presents the results of estimation of Equation (3). The results show a positive relationship of daylight with births volatility. A later sunrise (associated with darkness in the morning) has a negative effect on the standard deviation of births, while a later sunset (associated with light in the evening) has a positive effect on the standard deviation of births. Volatility of rate of marriage is positively associated with volatility of births, but no interaction with sunrise and sunset time is observed.

Table 3: The effect of sunrise and sunset times on volatility of births

VARIABLES	(1) volBirths	(2) volBirths
$Sunrise^9ma$	-3.256***	-2.671***
	(0.410)	(0.506)
$Sunset^9ma$	3.477***	3.015***
	(0.410)	(0.503)
$volMarr^{10-24}$	0.0997***	-0.962
	(0.00830)	(1.064)
$Sunrise^9ma \times volMarr^{10-24}$		-0.139
		(0.0860)
$Sunset^9ma \times volMarr^{10-24}$		0.105
		(0.0859)
Observations	9,775	9,775
Number of region_id	85	85

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Proportion of days with daylight at a particular hour

Table 4 shows the results of estimation of Equation (4). The explanatory variables account for proportion of days in the month of conception with darkness (for morning hours) or light (for evening hours). Darkness in the morning is indeed associated with increased fertility and light in the evening is associated with a lower fertility, and the gap in the effects indicates, similarly to the results in Table 2, that the evening hours are more strongly than morning hours associated with fertility. Moreover, the effect of darkness is positively correlated with the hour of the day. Darkness at 8am is almost not associated with fertility, but the effect at 9am is one percent. The effect of light at 9pm is almost twice as strong as the effect of light at 7pm (3.7% versus 2.6% at 8pm and 2% at 7pm).

Trigonometric model of seasonal fertility

Using trigonometric function to model seasonal movement in fertility, Table 5 shows the results from stepwise forward selection where column (1) does not force any sunshine variables to be included, while column (2), (3) and (4) force the model to include Sunrise only, Sunset only and both Sunrise and Sunset, respectively. Marriage 10-24 months prior to the month of births is robustly correlated to fertility positively. The later the time of sunset significantly contributes to a reduction in numbers of births. Yet the effects of sunrise time is rather weak. It is not even significant at 10% level unless we force the stepwise procedure to include both $Sunrise^9$ and $Sunset^9$ together.

The effects of daylight by hour based on trigonometric regressions with stepwise forward selection is presented in Table 6. It is shown that an increase in proportion of days with daylight at 19:00 and 20:00 leads to significant reduction in fertility after controlling for

Table 4: Effects of daylight by hour on fertility

VARIABLES	(1) ln(Births)	(2) ln(Births)	(3) ln(Births)	(4) ln(Births)	(5) ln(Births)
dark8am_9months	0.00771				
	(0.00489)				
dark9am_9months		0.0110**			
		(0.00472)			
light19pm_9months			-0.0200***		
			(0.00538)		
light20pm_9months				-0.0260***	
				(0.00527)	
light21pm_9months					-0.0369***
					(0.00516)
ln(marriages10_24)	0.200***	0.196***	0.198***	0.182***	0.164***
	(0.0223)	(0.0223)	(0.0223)	(0.0226)	(0.0228)
Observations	10,690	10,690	10,690	10,690	10,690
Number of region_id	85	85	85	85	85

The explanatory variables relate to the proportion of days with daylight at a particular hour during the conception month.
The estimation method is AR(1) with fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Effects of sunrise and sunset times on fertility based on trigonometric regressions

	(1)	(2)	(3)	(4)
VARIABLES	ln(Births)	ln(Births)	ln(Births)	ln(Births)
$Sunrise^9$		-0.00168		-0.0380*
		(0.00764)		(0.0225)
$Sunset^9$	-0.0133*		-0.0252**	-0.0347*
	(0.00780)		(0.0105)	(0.0182)
$ln(Marr)$	0.942***	0.943***	0.943***	0.947***
	(0.0209)	(0.0209)	(0.0206)	(0.0195)
Forced variable(s)				$Sunrise^9$
to be included	-	$Sunrise^9$	$Sunset^9$	and $Sunset^9$
Observations	10,775	10,775	10,775	10,775
Number of region_id	85	85	85	85

Stepwise forward selection with GLM choosing sine and cosine of order 1 – 12, while linear and quadratic trends are dropped. *** p<0.01, ** p<0.05, * p<0.1

number of marriage and several orders of sine and cosine function. Such finding is consistent with the estimation based on the regional fixed effects with AR1 in Table 4. Nonetheless, the results on proportion of dark days at 08:00 and 09:00 are not the same between the two models.

Difference in differences and synthetic control models

The results of estimation of Equation (8) with a 5-degree polynomial time trend are summarized in Table 7. For regions that had a lower than in control regions time zone during the reform period, one can intuitively expect a higher birth rate because of an earlier sunset. We do not observe this effect. For regions that had a higher than in control regions time zone during the reform period, one can intuitively expect a lower birth rate. Indeed, we observe strong negative statistically significant effects for some all these regions. These coefficients are robust to the choice of sum of square thresholds. Thus, the results indicate elasticity to-

Table 6: Effects of daylight by hour on fertility based on trigonometric regressions

VARIABLES	(1) ln(Births)	(2) ln(Births)	(3) ln(Births)	(4) ln(Births)	(5) ln(Births)
dark8am_9months	-0.149**				
	(0.0709)				
dark9am_9months		-0.0851			
		(0.0575)			
light18pm_9months			-0.0334		
			(0.0227)		
light19pm_9months				-0.0509**	
				(0.0202)	
light20pm_9months					-0.0704**
					(0.0274)
ln(marriages10_24)	0.944***	0.942***	0.942***	0.942***	0.942***
	(0.0202)	(0.0207)	(0.0210)	(0.0209)	(0.0208)
Observations	10,775	10,775	10,775	10,775	10,775
Number of region_id	85	85	85	85	85

The explanatory variables relate to the proportion of days with daylight at a particular hour during the conception month.
Stepwise forward selection with GLM choosing sine and cosine of order 1 – 12, while linear and quadratic trends are dropped. *** p<0.01, ** p<0.05, * p<0.1

ward a lower birth rate when the time zone shifts up but much no elasticity toward a higher birth rate when the time zone shifts down.

Furthermore, Table 7 also presents the coefficients of the synthetic control. For nine out of eleven treated regions we manage to find a synthetic control such that the predicted monthly births in the pre-treatment period fit well the monthly births in the treated region. We do not observe a acute disagreement between these coefficients and the difference in differences coefficients.

In Figure 4, we plot an example of effect, identified by synthetic control. It corresponds to the reform in Zabaykayle. The control regions are Jewish Autonomics Oblast', Orenburg, and Bashkortorstan. The synthetic control procedure assigns following weights: 0.529 To the Jewish Autonomus Oblast', zero to Orenburg, and 0.471 to Bashkortorstan. The two vertical lines in the figure indicate the reform period, when the clock in Zabaykayle was significantly different from the control regions. The clock in the period to the left and to the right of the vertical lines is similar in Zabaykayle and the three control regions. The figure shows a 8-months moving average of births per 1,000 of population. The number of births is stripped from seasonal month averages over all data period. The moving average explains the observed "effect" of the reform a few months before it starts. One can see shifting the clock one hour forward is associated with a decrease of 0.07 in the monthly fertility. This effect is also observed in the post-treatment period, indicating a strong downward elasticity, different from upward elasticity.

Table 7: Summary of difference-in-differences and synthetic control coefficients

2010-2014 reform (time zone lower in treatment than in control regions)

region id	coeff. (DID)	sd. err. (DID)	N	number of control regions	coeff. (synth.)	average sunrise time (2006-2018)	average sunset time (2006-2018)
18	-0.00665	(0.0262)	570	4	-0.0435	7.408722	19.74847
20	-0.0704***	(0.0236)	1,026	8	none	7.230766	19.60136
63	-0.0350	(0.0269)	2,850	24	-0.0094	6.643969	18.98633
76	-0.00339	(0.0268)	2,166	18	0.0115	6.410962	18.80471
83	-0.0301	(0.0622)	228	1	none	6.001273	18.64036

2014-2016 reform (time zone lower in treatement than in control regions)

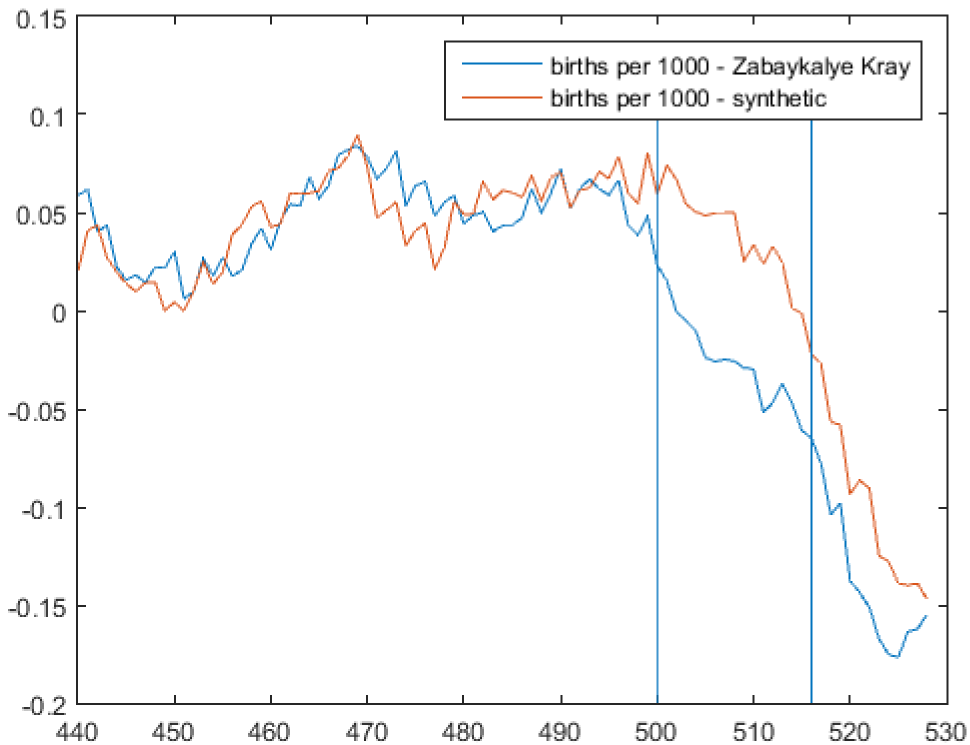
region id	coeff. (DID)	sd. err. (DID)	N	number of control regions	coeff. (synth.)	average sunrise time (2006-2018)	average sunset time (2006-2018)
12	-0.0457	(0.0350)	524	3	-0.0716	7.672014	20.00068
29	-0.0284	(0.0346)	1,188	8	-0.0777	7.121029	19.56617

2016 reform (time zone higher in treatment than in control regions)

region id	coeff. (DID)	sd. err. (DID)	N	number of control regions	coeff. (synth.)	average sunrise time (2006-2018)	average sunset time (2006-2018)
1	-0.0576	(0.0385)	2,888	18	-0.0173	6.956062	19.30019
4	-0.121***	(0.0446)	1,368	8	-0.0425	6.370551	18.64808
45	-0.0568	(0.0430)	1,824	11	none	6.816764	19.14478
77	-0.105***	(0.0332)	1,368	8	-0.0752	6.305963	18.66351
36	-0.0132	(0.0403)	3,648	23	0.0094	6.97584	19.34175
65	0.0632	(0.0441)	1,368	8	0.0233	6.426367	18.75065

Note: The table shows difference-in-differences coefficients. The estimation procedure is AR(1) The regression includes region-month fixed effects and regional 5-degree polynomial trend.

Figure 4: Synthetic control for Zabaykayle



The figure shows the monthly birth rate, net of long-run seasonal average, in Zabaykayle and in its synthetic control (see details in text). The horizontal axis shows months where 1 corresponds to January, 1974. The reform of 2014 that shifted the time zone in Zabaykayle up generated difference between the clock in Zabaykayle and in its synthetic control. This difference lasted until the reform of 2016. The period between the two reforms is indicated by two vertical lines.

5 Conclusions

Exploiting time zone reforms in Russia between 2010 and 2016 as natural experiments, this paper shows that more sunlight in the evening hours leads to a reduction in fertility, whereas volatility of fertility seems to increase with darkness. Although the effects of darkness in the morning hours are rather inconclusive, the effects of darkness in the early evening are robust to various model specifications commonly used in the literature. Our findings confirm existing evidence on the effects of sunlight on human reproductive behavior. Moreover, it emphasizes the role of time institution on fertility, which is relatively ignored so far. As several studies find the effects of sunlight exposure not only on fertility but also on infant and adult health, future researches along the same line of our paper could shade more light on causal effects of sunshine on these interesting subsequent outcomes as well.

References

Abadie, A., A. Diamond, and J. Hainmueller (2010): "Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program," *Journal of the American statistical Association*, 105, 493–505.

——— (2015): "Comparative politics and the synthetic control method," *American Journal of Political Science*, 59, 495–510.

Abadie, A. and J. Gardeazabal (2003): "The economic costs of conflict: A case study of the Basque Country," *American economic review*, 93, 113–132.

Balbuena, L. D., R. M. Middleton, K. Tuite-Dalton, T. Pouliou, K. E. Williams, and G. J. Noble (2016): "Sunshine, sea, and season of birth: MS incidence in Wales," *PloS one*, 11, e0155181.

Becker, S. (1981): "Seasonal patterns of fertility measures: theory and data," *Journal of the American Statistical Association*, 76, 249–259.

Beltran, A. J., J. Wu, and O. Laurent (2014): "Associations of meteorology with adverse pregnancy outcomes: a systematic review of preeclampsia, preterm birth and birth weight," *International journal of environmental research and public health*, 11, 91–172.

Bertrand, M., E. Duflo, and S. Mullainathan (2004): "How much should we trust differences-in-differences estimates?" *The Quarterly journal of economics*, 119, 249–275.

Conway, K. S. and J. Trudeau (2019): "Sunshine, fertility and racial disparities," *Economics & Human Biology*, 32, 18–39.

Cox, N. J. (2006): "Speaking Stata: In praise of trigonometric predictors," *The stata journal*, 6, 561–579.

Cummings, D. R. (2010): "Human birth seasonality and sunshine," *American Journal of Human Biology*, 22, 316–324.

Eubank, R. L. and P. Speckman (1990): "Curve fitting by polynomial-trigonometric regression," *Biometrika*, 77, 1–9.

Fellman, J. (2019): "Demographic Seasonality," *Twin Research and Human Genetics*, 1–8.

Irani, M. and Z. Merhi (2014): "Role of vitamin D in ovarian physiology and its implication in reproduction: a systematic review," *Fertility and Sterility*, 102, 460–468.

James, W. H. (1990): "Seasonal variation in human births," *Journal of Biosocial Science*, 22, 113–119.

Miron, J., D. A. Lam, K. L. Campbell, and J. W. Wood (1994): "Global Patterns of Seasonal Variation in Human Fertility," *Human Reproductive Ecology: Interactions of Environment, Fertility, and Behavior*.

Sellers, S. and C. Gray (2019): "Climate shocks constrain human fertility in Indonesia," *World Development*, 117, 357–369.

Trudeau, J., K. S. Conway, and A. Kutinova Menclova (2016): "Soaking up the sun: The role of sunshine in the production of infant health," *American Journal of Health Economics*, 2, 1–40.

Verheul, F., J. Smolders, M. Trojano, V. Lepore, C. Zwanikken, M. Amato, F. Grand'Maison, H. Butzkueven, M. Marrosu, P. Duquette, et al. (2013): "Fluctuations of MS births and UV-light exposure," *Acta Neurologica Scandinavica*, 127, 301–308.