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The impact of daylight on suicide rates

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ABSTRACT

Since Durkheim and Morselli found a spring peak in suicides in the late 19th century, researchers have presented possible explanations, including daylight variation, for this seasonal pattern. Our identification strategy exploits the idiosyncratic variation in daylight within Norwegian regions, arising from the country's substantial latitudinal range. We use full population data for a period of 45 years in a pre-registered research design. We find a small and non-significant relationship: One extra hour of daylight increases the suicide rate by merely 0.75 % (95 % CI: −0.4 % to 1.9 %).

1. Introduction

Durkheim (1897) and Morselli (Seregi et al., 2017) were among the first to find a seasonal pattern with a spring peak in suicide incidence. Several researchers have later confirmed this seasonal pattern (Preti and Miotto, 1998; Christodoulou et al., 2012; White et al., 2015; Seregi et al., 2017). Bramness et al. (2015) found evidence of a seasonal pattern for suicides in Norway, with a clear spring peak and a smaller autumn peak. However, they found a weakening of the pattern over the (nearly) four decades they studied, with a clearer seasonal pattern at the beginning of the period (1969 and onwards) than at the end (towards 2007).

A substantial body of research has found support for a positive correlation between daylight and suicides, with evidence from both the northern (Vyssoki et al., 2014; Papadopoulos et al., 2005; Partonen et al., 2004; Petridou et al., 2002) and southern hemisphere (Lambert et al., 2003). Certain studies have found statistical support for the hypothesis that more daylight increases the probability of violent suicides (Vyssoki et al., 2012; Preti and Miotto, 1998; Maes et al., 1994; Linkowski et al., 1992) but not so for non-violent suicides. Souêtre et al. (1989) found support for a negative correlation.

Our identification strategy exploits the idiosyncratic variation in daylight within Norwegian regions. The elongated shape and geographic location of Norway (58–72° N) make it especially suitable for studying effects of (extreme) variation in daylight on suicides. In the north, one never sees the sun during the darkest winter months. In the summer, the sun never sets. In the south of Norway, there is neither midnight sun, nor polar nights but the longest day exceeds the shortest by more than 12 h. Great variation in hours of daylight causes considerable variation in its marginal change. We use full population data for a period of 45 years in a pre-registered research design.

Whether our results are generalisable to other countries with less daylight variation remains an open question. The amount of such variation within Norway is substantial, from 24 h in the north to ~12 h in the south. For comparison, the within-year daylight variation is ~9 h in Berlin, ~10 h in Ushuaia (the world's most southern city) and less than 2 min in Quito, the city closest to equator.[1] With our identification strategy we are not able to say whether the results are driven by the extreme variation in the north or more moderate variation in the south. The external validity beyond the high north is thus uncertain.

The number of suicides per year in Norway has remained unchanged from 1995 to 2015, despite targeted efforts to prevent and reduce suicides in this period. Suicide prevails as the number one cause of death for men aged 15–49 in all the Nordic countries and for women aged 15–49 in Norway, Sweden, and Finland (NIPH, 2016). The loss of life, and the life-long grief for the bereaved, is a strong motivator for looking at these tragic events from all possible angles. This article addresses the debate on the effect of daylight and climatic factors on suicides.

We pre-registered the project with Open Science Framework[2] (OSF) 23 September 2020 with a detailed description of the models, hypotheses, variables and subgroup estimations. Preregistering increases

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[1] We are grateful to Andreas Kotsadam for recommendation and advice regarding the pre-registering of our analysis plan, to Simen Markussen for contributing to the concept of the article and for statistical advice, and to Tonya Moen Hansen for extracting the weather data from the Frost API solution.

[1] https://www.timehubzone.com's Sun Calculator.

[2] https://doi.org/10.17605/OSF.IO/M8CUW

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transparency and commits researchers to the analysis plan. Preregistering can be especially beneficial for null findings, as well as preventing model manipulation and significance fishing ("p-hacking").

Our original idea was to use days as our time unit. On average, there are 500–600 suicides in Norway each year, and approximately 400 municipalities. On any given day, the suicide rate in most municipalities is (fortunately) zero. However, this caused unnecessary noise in the estimations without adding substantial information. Substituting daily with weekly suicide rates and daylight (change) did not affect our main findings. Also, instead of creating age groups for men and women separately (ten groups in all), we kept the age groups aggregated across genders. The age group estimations show a substantial increase in uncertainty, which would only increase if we were to estimate suicide rates for even smaller age groups (divided by gender). By refraining from estimating another five coefficients, we also reduce the possibility of finding significant coefficients without there being a true statistical correlation (statistically, one may expect 5 % of the coefficients to be significant with a 95 % significance level).

Fig. 1 shows the extreme variation in daylight and daily change for three Norwegian municipalities. From Mandal in the south, to Gamvik in the north, with the Polar Circle passing through Traena. The left panel shows the daily amount of daylight hours for the three municipalities. The right panel shows the daily change in daylight hours. The x-axis represents a year, from January through December.

The equinoxes, when day and night are of equal length, are usually around 21 March and 23 September in the Northern hemisphere. Summer solstice, the longest day (and shortest night), falls on June 21 or 22. Winter solstice, the year's shortest day (and longest night), usually falls on December 21 or 22. At the solstices, the change in daylight is zero.

In the north of Norway, where there is midnight sun and polar nights, the rate of change in daylight peaks four times a year; at the onset and end of the polar nights, and at the onset and end of the midnight sun. The equinoxes and solstices occur between these peaks. We exemplify this with Gamvik in Fig. 1. The rates of change are much less pronounced in Traena, and even less so in Mandal.

If *absolute amounts* of daylight affect suicide rates, one may expect distinct differences between Norwegian municipalities depending on their inhabitants' exposure to daylight. If daylight increases impulsivity and violent suicides, one may expect a higher incidence further north, during the midnight sun, when the sun never sets, compared to the southern parts of Norway. If daylight *change* is more important, suicides should peak around the time of the greatest changes. In the north, there are four pronounced peaks per year. As one moves south, the peaks become less pronounced. Do these peaks affect suicide rates differently in different parts of the country, and may (changes in) daylight be the reason for this?

There are several similarities between our study and White et al. (2015). They use suicide data from three different countries with markedly different daylight profiles, i.e. Australia, Greece and Norway, to disentangle seasonality and sunlight. The idea relates closely to our design. However, when comparing suicide rates across countries, other factors come into play. Public holidays often fall on different days, causing variation in each country's seasonality. One may also argue that the extreme difference in daylight and daylight change between Oslo (Norway's capital) and Gamvik is greater than the differences in sunlight profiles in Oslo, Athens and Melbourne, chosen by White et al. (2015). Our study is much in the same spirit as that of White et al. (2015). Building on their work, while also extending the analyses with weather variables, we hope to provide an even more detailed answer to the questions concerning suicide, seasonality and sunlight.

The seasonal pattern in suicide cases applies to other (related) phenomena, such as hospital admissions for mania and depression (Morken et al., 2002) and violence (Morken and Linaker, 2000). Markussen and Røed (2015) identified a causal effect of daylight on worker's absenteeism due to illness. In this article, we study the impact of daylight on suicide rates. Following Markussen and Røed (2015) we estimate a linear regression model with week- and municipality-fixed effects. This leaves us with the seasonal variation in daylight as our effect of interest.

1.1. Suicide prevention

The article forms part of the project "Treatment pathways for suicide victims and suicide bereaved", a continuation of an already ongoing project (at the National Institute of Public Health, NIPH, 2016) both focussing on suicide prevention. Data are already available and several research articles based on these data are published (Hauge et al., 2018; Øien-Ødegaard et al., 2019; Christiansen et al., 2020).

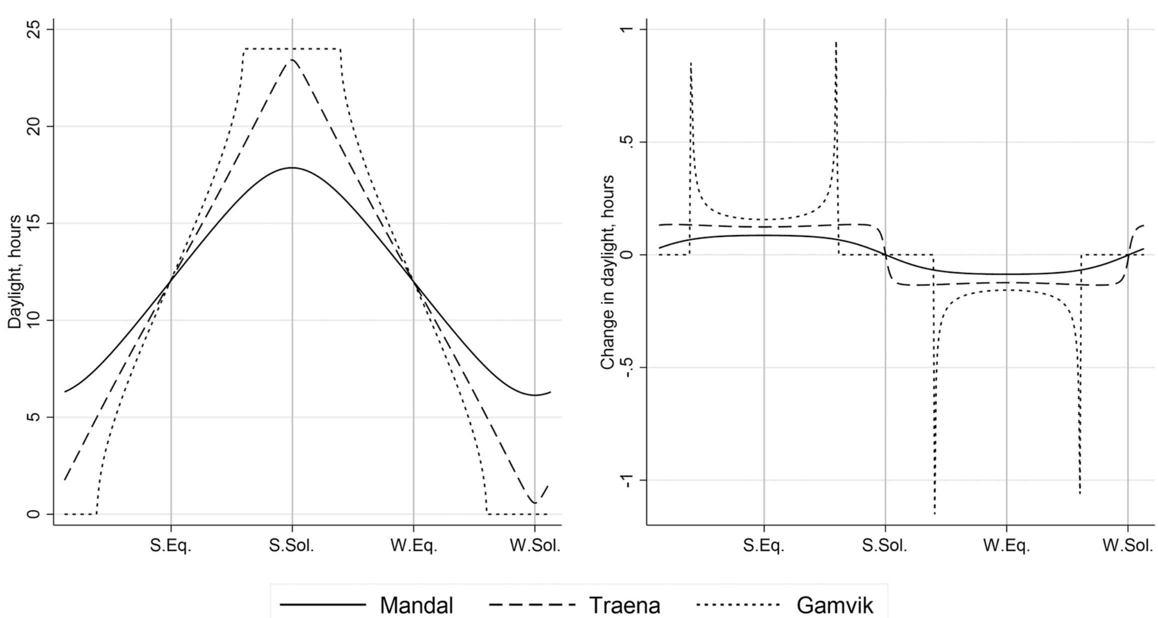

Fig. 1. Daylight (left panel) and change in daylight (right panel), throughout the year, in three Norwegian municipalities, representing the south (Mandal), the middle (Traena) and the north (Gamvik). Summer equinox (S.Eq.), Summer solstice (S.Sol.), Winter equinox (W.Eq.), and Winter solstice (W.Sol.).

2. Data and coding of main variables

National registries gathered for administrative purposes, virtually attrition-free, provide full population data for cause of death and individual characteristics. The Cause of Death Registry starts in 1970, with data available through 2015 for this project. Place of residence is given at the end of each year. It is available through 2014 but unless people move, their place of residence remains unchanged in 2015. Equation *(i)* specifies the model for daily predictions of daylight for each municipality, according to their latitude and the calendar day (soldag), following the daylight model used by Markussen and Røed (2015):

(i) Daylight = 24 *acos(1-max(min(1-tan(lat)*tan(axis*cos(j * soldag)),2),0))/_pi

lat = ([the municipality's latitude]*pi)/180, *axis* = (23.439 *pi)/180, *j* = pi/182.625 and *soldag* = calendar day (the complete Stata code can be found in the appendix).

We estimate weekly suicide rates for each municipality, dividing the weekly number of suicides by the number of inhabitants for the respective year. Population numbers are given at the end of each year (coding of suicides (A.1), and dependent variables and covariates (A.2) are shown in the appendix).

If suicide rates and daylight correlate, we ought to see a seasonal pattern in suicide rates in Norway. The bars in Fig. 2, depict weekly suicide rates in Norway per 1 000 000 inhabitants (left axis), averaged over all the years in our data set (1970–2015). The dashed line shows the average weekly hours of daylight through the year (right axis).

The bars in Fig. 2 suggest a seasonal pattern in suicide rates in Norway, as described in the literature. There is a spring peak between April and June (when daylight grows), but the second highest peak is in the last week of December and the first week of January. Suicide rates are lowest just before and after the turn of the year. There is also a smaller autumn peak in August and September (when daylight dwindles), preceded by lower suicide rates in July. If daylight affects seasonal variation in suicide rates, one may expect a clearer pattern in the northernmost parts of Norway, where daylight varies more.

To provide a graphical exposition of the identification strategy, we construct the same graph for the southern, mid and northern parts of Norway separately, as displayed in Fig. 3. Note first the substantial difference in the daylight pattern over the year, with considerably more variation in the northern regions than in the south. The difference in daylight between the shortest and longest day (the maximum difference) is ~12 h in the south, and 24 h in the north. A strong relationship between daylight and suicides should then imply a more pronounced seasonal pattern in suicides in the north than in the south.

In South Norway, suicide rates have their highest peak in spring, with smaller peaks in autumn and at the turn of the year, resembling the main pattern shown in Fig. 2. Mid Norway shows less evidence of a seasonal pattern. Instead, there are several peaks spread throughout the year. North Norway's suicide rates are closer to the main pattern but its second highest peak is the last week of the year. One cannot easily conclude from Fig. 3 that there is a clearer seasonal pattern in the north of Norway.

3. Model specification and empirical strategies

Our main hypothesis is that suicide rates depend on daylight. Daylight reflects the hours the sun is up. We can thus think of it as potential hours of sunshine or the hours of sunshine on a clear day. Daylight may affect suicides either in absolute value (level) or through the change in daylight. The research questions we address, specified in the pre-analysis plan, are:

Hypothesis 1. Is there a relationship between the *level* of daylight (hours per day) and suicide rates?

Hypothesis 2. Is there a relationship between the *change* in daylight and suicide rates?

a. If so, is it symmetrical? This would imply that if the suicide incident increases in spring, it should decrease by the same amount in autumn (or vice versa).
b. Is it asymmetrical, hence does not follow the same pattern?

In our main hypotheses testing, we consider the effect of daylight on the total suicide rate. Our baseline model includes two extensive control sets. First, we include fixed effects for *municipality x year*. This serves two purposes: Within a year it absorbs all time-invariant variation across space. Across years, the formulation with year-specific coefficients for each municipality also absorbs all long-run changes between municipalities, originating e.g. from demographic changes. Second, the model also includes *week*-specific fixed effects. This absorbs all place-invariant variation across time, such as Christmas holidays. The model thus allows us to test the correlation between the idiosyncratic variation in daylight and suicides. The identifying assumption is that any such correlation is causal and not due to within-year confounders. The arguably most likely such confounder is weather. We therefore extend the model with controls for air temperature, precipitation and hours of sunshine to test its importance (see details below under "Suicide and climatic factors"). Our linear regression model, addressing research question 1, is as follows:

$$\text{Suicide}^{m,t} = \beta\text{Daylight}^{\text{hours}} + \gamma[\text{Municipality x Year}] + \mu\text{Week} + \varepsilon \qquad (1)$$

Suicide is municipality *m*'s suicide rate in week *t*. *Daylight* denotes the average hours of daylight per week. *Municipality x Year* and *Week* are fixed effect vectors.

To answer research question 2, we use the change in daylight, denoted *d(Daylight)*:

$$\text{Suicide}^{m,t} = \beta d(\text{Daylight}^{\text{hours}}) + \gamma[\text{Municipality x Year}] + \mu\text{Week} + \varepsilon \qquad (2)$$

Do suicide rates change by the same amount when daylight increases, as when it decreases? We test for symmetry with separate estimations for the year's first six months, when daylight grows, and its last six months, when daylight wanes. The model is otherwise identical to Eq. (2), denoted *(2a)* and *(2b)*.

Finally, we estimate the effect of daylight on suicide rates in nine subgroups; men, women, violent and non-violent suicides, and five age groups; (1) 18–29, (2) 30–39, (3) 40–49, (4) 50–67 and (5) 67 + .

4. Results from the main analyses

Table 1 displays the results for the main model. We find a small (0.0176) and non-significant relationship for absolute amounts of daylight; one extra hour of daylight increases the suicide rate by just 0.0176/2.33 * 100 = 0.75 %, where 2.33 is the average suicide rate per 1 000 000 inhabitants. Given the estimated standard error, there is a 95 % probability that the relative effect of one more hour of daylight lies somewhere between 1.9 % and −0.4 % (0.0176+/−1.96 *0.0137). Standard errors are clustered at municipality x year level.

The next columns show results for the effect of daylight change on suicide rates throughout the year *(2)* and for the first *(2a)* and last *(2b)* six months of the year. Daylight change for the whole year and the last six months suggest a positive effect, while daylight change in the first six months suggests a negative effect, but the results are not statistically significant (t-values between −1 and 1). None of the results lends support, on any relevant statistical scale, to the hypotheses that more daylight (absolute or measured as change) increases suicide rates.

R-squared and adjusted R-squared are 0.0220 and 0.0028 for Hypotheses 1 and 2. R-squared increases to 0.0417 and 0.0415 for Hypotheses 2a and 2b, and adjusted R-squared to 0.0033 and 0.0031. The number of observations (N) are the product of 45 years (1970–2015), 52 weeks (per year) and ~435 municipalities for Hypotheses 1 and 2. When estimating Hypotheses 2a and 2b the number of weeks is 26. Results

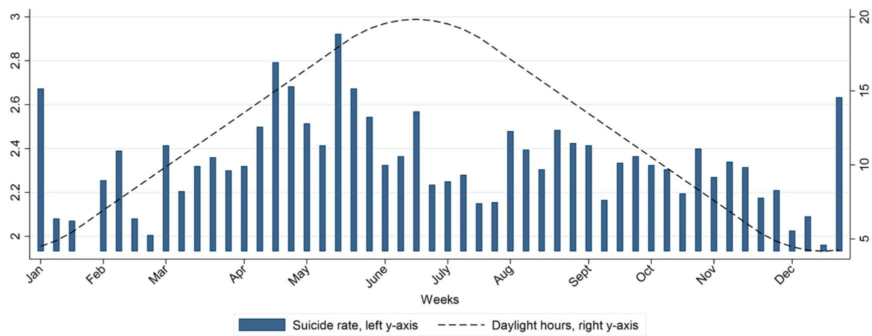

Fig. 2. Weekly suicide rates and daylight hours in Norway averaged over 1970–2015.

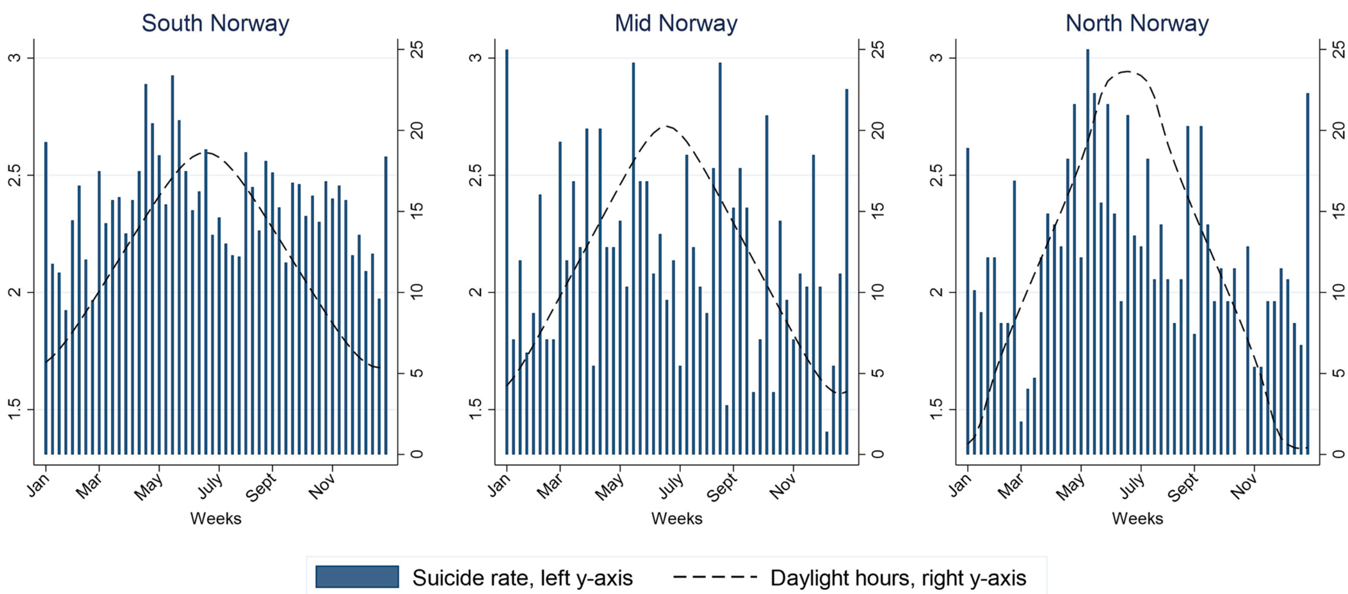

Fig. 3. Weekly suicide rates and daylight hours for South, Mid and North Norway averaged over 1970–2015.

Table 1
Results from the main analyses, Hypothesis 1 (level of daylight (hours per day) and suicide rates), 2 (change in daylight and suicide rates), 2a (symmetrical), and 2b (asymmetrical), without and with(^{w}) weather variables.

	Hypothesis 1		Hypothesis 2		Hypothesis 2a		Hypothesis 2b	
Variable	**(1)**	**(1^{w})**	**(2)**	**(2^{w})**	**(2a)**	**(2a^{w})**	**(2b)**	**(2b^{w})**
Daylight	0.0176	0.0106						
Std. Error	*0.0137*	*0.0138*						
t-value	*1.2827*	*0.7659*						
Daylight change			0.0593	0.0631	-0.0443	-0.0288	0.1288	0.1324
Std. Error			*0.0762*	*0.0763*	*0.1474*	*0.1474*	*0.1483*	*0.1482*
t-value			*0.7780*	*0.8274*	*-0.3005*	*-0.1954*	*0.8684*	*0.8932*
Weather controls	No	Yes	No	Yes	No	Yes	No	Yes
N	1 019 356	993 044	1 018 928	992 627	509 250	496 105	509 678	496 522
R-squared	0.0220	0.0221	0.0220	0.0221	0.0417	0.0418	0.0415	0.0417
Adj. R-sq.	0.0028	0.0029	0.0028	0.0029	0.0033	0.0034	0.0031	0.0033

from the analyses with weather variables are included in Table 1 to facilitate comparison. There are somewhat fewer observations when we control for weather due to missing values for some municipalities.[3]

In Fig. 4, we show the predicted suicide rate from daylight (whole line), together with suicides per million (bars), and hours of daylight (dashed line). The shaded area shows the confidence interval for the predicted suicide rate. If the estimated coefficient were zero, the predicted correlation between daylight and suicide would be a flat line, equal to the average suicide rate (~2.3). What can we conclude from Fig. 4? The confidence interval includes the hypothetical flat line, i.e. it includes zero. Thus, we cannot reject the hypothesis that there is no correlation between daylight and seasonal variation in suicide rates. On the other hand, imagine a line following (the outer band of the) confidence interval's maximal curvature. This line suggests that daylight

[3] Very few weather stations measure the daily amount of sunshine, thus this variable had very few observations. We estimated the model on the same sample without weather controls to be sure the results with weather were not driven by a change in sample composition; the results are almost identical.

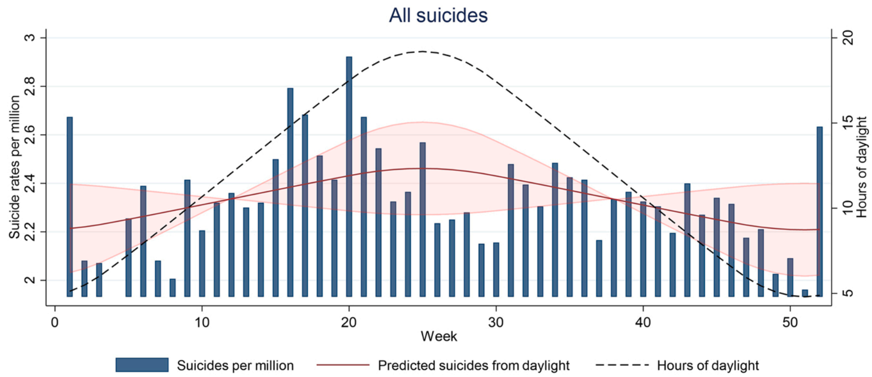

Fig. 4. Suicide rates per million (bars), hours of daylight (dashed line) and predicted suicides from daylight (whole line), with confidence interval (shaded area). The confidence interval includes zero (no correlation) but may also suggest some correlation between daylight and seasonal variation in suicide rates.

explains a substantial share of the seasonal variation in suicide rates. Thus, the confidence interval allows for both a substantial *and* no correlation.

Multiplying the relative effect with the maximum difference in daylight (~12 h in South Norway, even more further north), gives us an increase of ~11 %. Using the standard error, as above, we can say with 95 % certainty that the effect of the maximum difference in daylight hours on the suicide rate lies between 22.8 % and −4.8 %.

From Fig. 4 we can see that the first and the last week of the year stand out with relatively high suicide rates. As the model fully controls for week-specific effects, any common peaks in suicides across place are absorbed in the model and should thus create no bias in the estimation. In Fig. 3, above, we see that mid-Norway stands out with particularly high suicide rates at the turn of the year, indicating that these peaks are not place-invariant. As a robustness check we thus also estimated all models in Table 1, excluding weeks 1 and 52.

For the model relating to Hypothesis 1, this results in somewhat larger coefficients, almost significantly different from zero without weather variables, clearly non-significant when weather variables are included. For the other models the changes in coefficients are minor.[4] Although this reduced uncertainty and shrank the 95 % confidence intervals, they still included zero, leaving the main result unchanged.

To investigate robustness under alternative functional forms we also estimate the negative binomial model on count data. This did not result in a significant relationship between daylight and (the number of) suicides on any conventional level, and thus confirms the main findings in Table 1. Results are available upon request.

4.1. *Suicide and climatic factors*

Several studies investigate the relation between suicide and climatic factors, such as temperature, storms and humidity. Deisenhammer et al. (2003), Lin et al. (2008) and Lee et al. (2006) found a positive correlation with temperature, Deisenhammer et al. (2003) also with storms, and Lee et al. (2006) with humidity. The latter is contrary to Linkowski et al. (1992), who found a negative correlation between suicides and humidity. Ajdacic-Gross (2007) and Tsai (2010), however, found little contribution from meteorological variables on suicide.

Weather data from the Frost API solution[5] was added as control variables to the models (1, 2, 2a, and 2b). Since one weather station serves several municipalities, we assigned weather stations by proximity, measured as the crow flies, each year (some stations are discontinued, others emerge). This ensured a high degree of weather data validity. We retrieved data on precipitation, air temperature, and sunshine, which together provide a good overall impression of the weather conditions. Precipitation and sunshine, measured in millimetres and hours, are summed over the last 24 h. The air temperature is an arithmetic mean of 24 hourly values, measured in degrees Celsius. Although the data coverage was quite good there were some missing values and a few instances where a weather station could not be assigned. This explains why there are slightly fewer observations (N) when controlling for climatic factors (cf. Table 1).

Adding temperature, precipitation and sunshine to the control variables causes minor changes in the effect of (absolute amount or change in) daylight and suicide rates. The confidence intervals still include zero, thus controlling for weather does not alter the main results.

4.2. *Subgroup estimations*

Up until this point, we have used the total suicide rate without differentiating between subgroups. A theory proposed by several researchers, is that daylight affects serotonin levels in the blood (Petridou et al., 2002; Papadopoulos et al., 2005), or the neuronal activity in the brain (Lambert et al., 2003), and increases the propensity for impulsive actions. Some argue that men are more impulsive than women are, which explains significant results from daylight on male suicides but less so for female suicides (Preti and Miotto, 1998).

Several researchers argue that impulsive actions, relating to daylight and serotonin levels, explain why there is a significant correlation between daylight and violent suicides, and a non-significant relationship with non-violent suicides (Linkowski et al., 1992; Maes et al., 1994; Preti and Miotto, 1998; Lin et al., 2008; Reutfors et al., 2009; Vyssoki et al., 2012).

Impulsivity may also change throughout one's life course. Preti and Miotto (1998) find stronger evidence of seasonality in older age groups. We investigate the effect of daylight and daylight change on men and women, on violent and non-violent suicides, and on five distinct age groups. We also did a sub-analysis of violent suicides amongst men and violent suicides defined as only guns and hanging.

4.2.1. *Estimations for subgroup I: Men and women*

Does daylight affect men and women differently? We repeat the estimations, replacing the total suicide rate with separate suicide rates for men and women. In Fig. 5, we show suicide rates per million (bars), predicted seasonal variation in suicides (whole line) with confidence intervals (shaded area), and weekly daylight (dashed line), for men and women separately.

Suicide rates amongst men are higher than suicide rates for women (scales differ on the y-axes). Men have a somewhat clearer seasonal pattern, with peaks in spring and at the turn of the year. Women have a small peak in spring and in the year's last week.

[4] These results are available upon request.

[5] https://frost.met.no/index.html

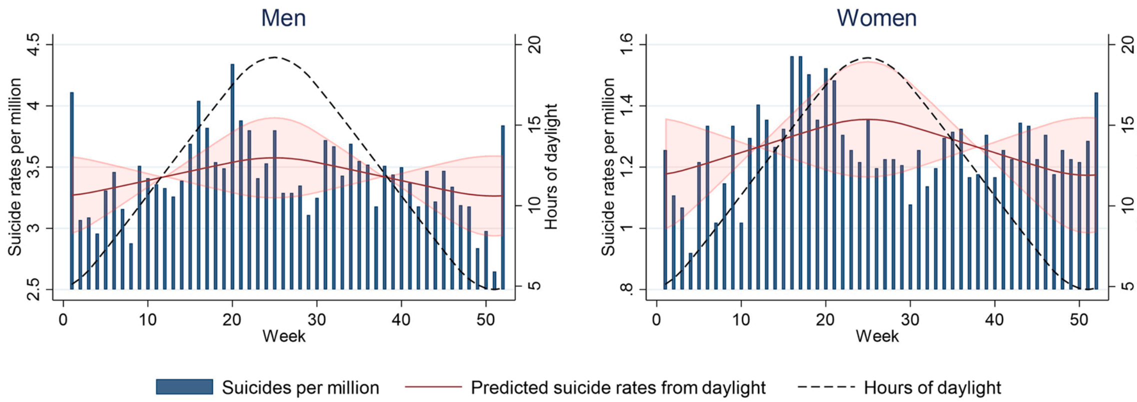

Fig. 5. Suicide rates per million (bars), hours of daylight (dashed line) and predicted suicides from daylight (whole line), for men and women, with confidence interval (shaded area). Y-axes have different scales.

4.2.2. Estimations for subgroup II: Violent and non-violent suicides

To our knowledge, there is no finite consensus on how to group violent and non-violent suicides. Ludwig and Dwidedi (2018) present Asberg's criteria, where hanging, firearms, jumping from heights or under a train, deep cuts, car crash, burning, gas poisoning, drowning and electrocution are considered violent suicides, while drug overdoses are non-violent suicide attempts. According to Ludwig and Dwidedi (2018), many researchers use these criteria when separating violent from non-violent suicides. However, Asberg's criteria rely on relatively detailed information, not necessarily available from the ICD codes in a country's cause of death registry. Maes et al. (1994) and Reutfors et al. (2009) use ICD-10, and consider all methods as violent, except poisoning. Dumais et al. (2005) and Bramness et al. (2015) consider poisoning and drowning as non-violent. In a bulletin by the WHO, Ajdacic-Gross et al. (2008) consider poisoning and drowning less violent and less lethal than suicide by firearm or hanging. We choose to follow the latter examples, classifying poisoning and drowning as non-violent methods, relying on the ICD codes found in the Cause of Death Registry (cf. Table A1).

In Fig. 6, we show suicide rates per million (bars), predicted seasonal variation in suicides (whole line) with confidence intervals (shaded area), and weekly daylight (dashed line), for violent and non-violent suicides.

Violent and non-violent suicides display a seasonal pattern, with peaks in spring and at the turn of the year. The shaded area shows the confidence interval for the predicted suicide rate. As in Fig. 4, the confidence intervals include the hypothetical flat line. Thus, we cannot reject the hypothesis that there is no correlation between daylight and seasonal variation in either violent or non-violent suicide rates. The outer bands of the confidence intervals' maximal curvatures suggest that daylight partly explains the seasonal variation in violent and non-violent suicide rates. Thus, the confidence intervals allow for both zero and a substantial correlation.

4.2.3. Estimations for subgroup III: Age groups

An extension of this analysis is to investigate differences between age groups. Thus, we will estimate daylight effects on suicide rates for five separate age groups: (1) 18–29, (2) 30–39, (3) 40–49, (4) 50–67 and (5) 67 + .

4.3. Visual presentation of the estimation results, plotting coefficients with 95 % confidence intervals

Fig. 7 visualises the results for all suicides and the nine subgroups (men, women, violent, non-violent, age groups 1–5), displaying the estimated coefficients for daylight and change in daylight (all year, first six and last six months), with 95 % confidence intervals. The majority of the coefficients are very near zero, and the majority of the confidence intervals include zero, thus we cannot reject the null hypothesis (no correlation between daylight and suicide rates). We show results from the regression analyses for all subgroups in the appendix (Table A.4.1-A.4.6).

As previously mentioned, we are interested in whether suicide rates change by the same amount when daylight increases (in spring) as when it decreases (in autumn). The results for all suicides, and for the subgroups men, women, violent and non-violent suicides, do not support either symmetry or asymmetry; the coefficients are very near zero and the confidence intervals include zero. With two exceptions, this also

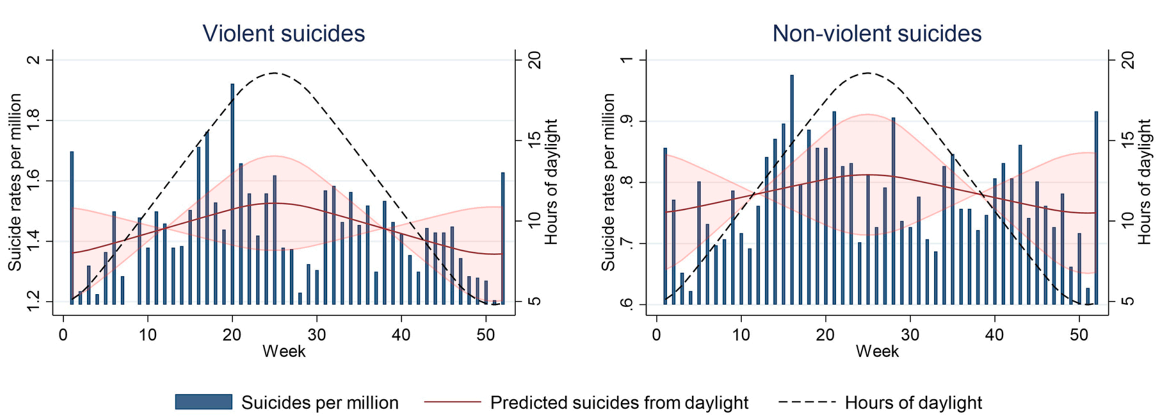

Fig. 6. Suicide rates per million (bars), hours of daylight (dashed line) and predicted suicides from daylight (whole line), with confidence interval (shaded area), for violent and non-violent suicides. Y-axes have different scales.

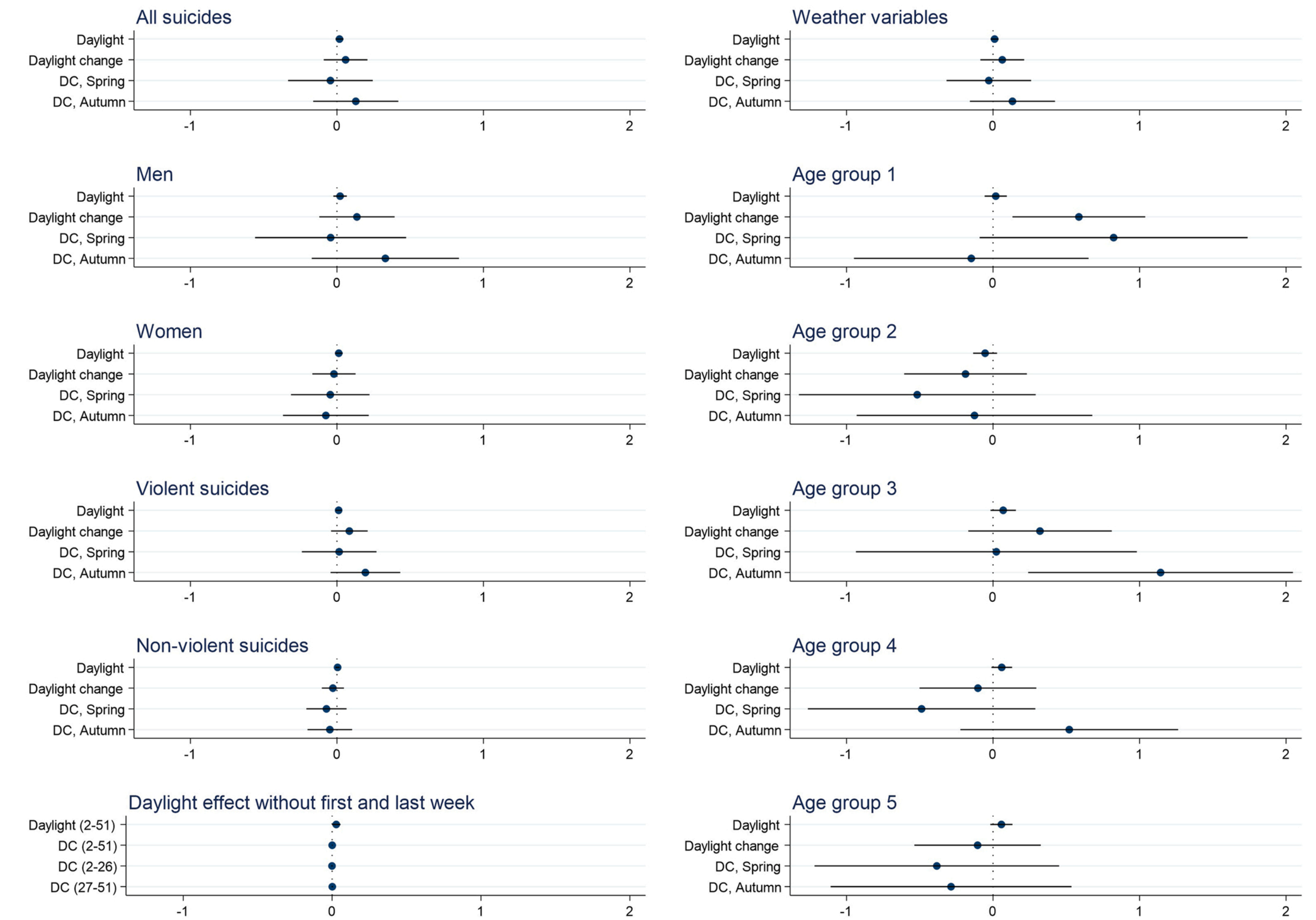

Fig. 7. Coefficient plot based on estimated results for the main model (daylight, daylight change all year, Hypotheses 1, 2, 2a, and 2b) for all suicides, with weather variables, subgroups, and leaving out the first and last week of the year, with 95 % confidence intervals. The majority of the coefficients are close to zero. The majority of the confidence intervals include zero. DC = daylight change.

applies to the results for the five age groups. When estimating 20 coefficients, one may expect at least one significant result. In our case, we have two, but we must consider them in light of the overall results. Our main result suggests that the effect of daylight on suicides is very near zero. A zero average may mask an underlying result where younger age groups' coefficients were positive and older age groups' were negative, but our results vary from age group to age group. We cannot rule out that there may be a stronger correlation of daylight on these particular age groups, but our results do not allow us to draw any clear conclusions in this direction.

Although not part of the pre-analysis plan, we investigated the effect of daylight on violent suicide amongst men (cf. Preti and Miotto, 1998). The results showed a coefficient of 0.42 for daylight change in the autumn (Hypothesis 2b), and a t-value of 1.89. The lower end of the confidence interval includes zero (with 95 % probability the effect lies between −0.015 and 0.856). With no finite consensus on the definition of violent (and non-violent) suicides, we also explored an alternative classification where only guns and hanging were considered violent suicides, leaving out cutting and jumping. The highest level of significance was for daylight change in the autumn (Hypothesis 2b), with a coefficient of 0.2, and a t-value of 1.75. Again, the confidence interval includes zero (the effect lies between −0.024 and 0.152 with 95 % probability) leaving us inconclusive as to the true effect.

5. Conclusion

Since Durkheim and Morselli found a spring peak in suicides in the late 19th century, researchers have put forth possible theories and explanations for this surprising seasonal pattern. One set of explanations suggests a causal relation between daylight and suicides, but most studies lack an identification of causality. Our identification strategy exploits the idiosyncratic variation in daylight within Norwegian municipalities, arising from the country's considerable latitudinal range. Using full population data for a 45-year period, in a pre-registered research design, we completely control for place- and time-specific effects. The data show a spring peak, with a second peak at the turn of the year. However, we do not find significant statistical support for the hypothesis that variation in daylight explains these peaks and extending the analyses with weather variables does not alter this result. A zero average may mask a result where half the subgroup coefficients are positive and the other half negative. Our subgroup results do not display clear patterns but vary from group to group. With no clear pattern, there is little reason to emphasise the finding of two significant coefficients in two different subgroups, as this as about what we may expect from pure chance.

CRediT authorship contribution statement

Kjersti Helene Hernæs: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualisation. **Katrine Damgaard Skyrud:** Validation, Writing – review & editing.

Competing interests

The Norwegian Institute of Public Health funded the study. No external funding was received.

Appendix A

See Table A.4.1-A.4.6.

A.1 Coding of suicides.

Types of suicide, by ICD codes	ICD-8	ICD-9	ICD-10
Poison	E950-E952	E950-E952	X6
hanging	E953	E953	X70
drowning	E954	E954	X71
firearms/explosives	E955	E955	X72-X75
cutting	E956	E956	X78
jumping	E957	E957	X80
other/unspecified	E958-E959	E958-E959	X76-X77, X79, X81–84, Y870

A.2 Dependent variables and covariates.

Dependent variables			
	ICD-8	ICD-9	ICD-10
Suicide rate	E950-E959	E950-E959	X6, X70–84, Y870
Suicide rate, men	E950-E959	E950-E959	X6, X70–84, Y870
Suicide rate, women	E950-E959	E950-E959	X6, X70–84, Y870
Suicide rate, violent suicides	E953, E955-E957	E953, E955-E957	X70, X72-X75, X78, X80
Suicide rate, non-violent suicides	E950-E952, E954	E950-E952, E954	X6, X71
Covariates	**Unit**	**Min**	**Max**
Daylight	Hours	0	24
Change in daylight (d(Daylight))	Hours	-1.2407	+ 1.1807
Municipality (place of residence)	Indicator	0	1
Year	Indicator	0	1
Municipality*Year	Indicator	0	1
Week	Indicator	0	1
Precipitation	Millimetres	0	88.9
Air temperature	Degrees Celsius	-34.8	43.8
Sunshine	Hours	-0.4	24

A.3 Daylight model.

<u>Stata code for daylight estimation:</u>

```
forvalues k = 1/366 {.
gen d`k′ = 1.
}.
reshape long d, i(nr) j(daynr).
drop d.
gen soldag = dagnr+ 11.
replace soldag = soldag-365 if soldag > 365.
gen axis = (23.439 *_pi)/180.
gen j = _pi/182.625.
```

Table A.4.1
Results for Hypotheses 1, 2, 2a, and 2b for men (M) and women (W).

Variable	M (1)	W (1)	M (2)	W (2)	M (2a)	W (2a)	M (2b)	W (2b)
Daylight	0.0216	0.0127						
Std. error	*0.0235*	*0.0135*						
t-value	*0.9210*	*0.9397*						
Daylight change			0.1364	-0.0203	-0.0430	-0.0456	0.3307	-0.0755
Std. error			*0.1312*	*0.0753*	*0.2630*	*0.1368*	*0.2563*	*0.1493*
t-value			*1.0399*	*-0.2690*	*-0.1636*	*-0.3333*	*1.2903*	*-0.5056*
N	1 019 356	1 019 304	1 018 928	1 018 876	509 250	509 224	509 678	509 652
R-squared	0.0213	0.0209	0.0213	0.0209	0.0409	0.0405	0.0408	0.0401
Adj. R-sq.	0.0020	0.0016	0.0020	0.0016	0.0025	0.0020	0.0024	0.0017

Legend: ∘ $p < 0.10$, * $p < 0.05$

Table A.4.2
Results for Hypotheses 1, 2, 2a, and 2b for violent (VS) and non-violent suicides (NVS).

Variable	VS (1)	NVS (1)	VS (2)	NVS (2)	VS (2a)	NVS (2a)	VS (2b)	NVS (2b)
Daylight	0.0117	0.0043						
Std. error	*0.0112*	*0.0071*						
t-value	*1.4 273*	*0.61 464*						
Daylight change			0.0849	-0.0276	0.0153	-0.0715	0.1945	-0.0486
Std. error			*0.0638*	*0.0386*	*0.1300*	*0.0700*	*0.1214*	*0.0777*
t-value			*1.3305*	*-0.7143*	*0.1175*	*-1.0207*	*1.6014*	*-0.6251*
N	1 019 356	1 019 356	1 018 928	1 018 928	509 250	509 250	509 678	509 678
R-squared	0.0211	0.0218	0.0211	0.0218	0.0406	0.0412	0.0409	0.0407
Adj. R-sq.	0.0019	0.0025	0.0019	0.0025	0.0021	0.0028	0.0025	0.0023

Legend: ∘ $p < 0.10$, * $p < 0.05$

Table A.4.3
Results for Hypothesis 1 for age groups (AG) 1–5.

Variable	AG1 (1)	AG2 (1)	AG3 (1)	AG4 (1)	AG5 (1)
Daylight	0.0184	-0.0542	0.0694	0.0594∘	0.0569
Std. error	*0.0386*	*0.0417*	*0.0440*	*0.0358*	*0.0387*
t-value	*0.4771*	*-1.2985*	*1.5770*	*1.6594*	*1.4724*
N	1 019 304	1 019 304	1 019 044	1 019 304	1 019 304
R-squared	0.0199	0.0197	0.0198	0.0203	0.0202
Adj. R-sq.	0.0007	0.0005	0.0006	0.0010	0.0009

Legend: ∘ $p < 0.10$, * $p < 0.05$

Table A.4.4
Results for Hypothesis 2 for age groups (AG) 1–5.

Variable	AG1 (2)	AG2 (2)	AG3 (2)	AG4 (2)	AG5 (2)
Daylight change	0.5859 *	-0.1879	0.3205	-0.1033	-0.1056
Std. error	*0.2313*	*0.2136*	*0.2499*	*0.2034*	*0.2200*
t-value	*2.5325*	*-0.8794*	*1.2826*	*-0.5079*	*-0.4798*
N	1 018 876	1 018 876	1 018 613	1 018 876	1 018 876
R-squared	0.0200	0.0198	0.0198	0.0203	0.0202
Adj. R-sq.	0.0007	0.0005	0.0006	0.0010	0.0009

Legend: ∘ $p < 0.10$, * $p < 0.05$

Table A.4.5
Results for Hypothesis 2a for age groups (AG) 1–5.

Variable	AG1 (2a)	AG2 (2a)	AG3 (2a)	AG4 (2a)	AG5 (2a)
Daylight change	0.8230∘	-0.5176	0.0226	-0.4877	-0.3840
Std. error	*0.4667*	*0.4125*	*0.4893*	*0.3961*	*0.4259*
t-value	*1.7632*	*-1.2547*	*0.0463*	*-1.2312*	*-0.9014*
N	509 224	509 224	509 091	509 224	509 224
R-squared	0.0392	0.0389	0.0394	0.0400	0.0395
Adj. R-sq.	0.0006	0.0004	0.0009	0.0016	0.0010

Legend: ∘ $p < 0.10$, * $p < 0.05$

Table A.4.6
Results for Hypothesis 2b for age groups (AG) 1–5.

Variable	AG1 (2b)	AG2 (2b)	AG3 (2b)	AG4 (2b)	AG5 (2b)
Daylight change	-0.1486	-0.1266	1.1436 *	0.5203	-0.2865
Std. error	*0.4086*	*0.4102*	*0.4611*	*0.3793*	*0.4194*
t-value	*-0.3637*	*-0.3086*	*2.4804*	*1.3716*	*-0.6832*
N	509 652	509 652	509 522	509 652	509 652
R-squared	0.0391	0.0390	0.0391	0.0394	0.0393
Adj. R-sq.	0.0007	0.0005	0.0006	0.0009	0.0008

Legend: ∘ $p < 0.10$, * $p < 0.05$

gen lat = (lat_komsenter*_pi)/180.
gen daylight = 24 *acos(1-max(min(1-tan(lat)*tan(axis*cos(j * soldag)),2),0))/_pi.
A.4 Additional tables for subgroup estimation results.

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