Daylight Saving in GB; Is there evidence in favour of clock time on GMT?

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Executive Summary

Setting the clocks back to Greenwich Mean Time (GMT) after the end of British Summer Time is a historical institution that has not been subject to evidence-based policy assessment. This report examines evidence on the impact of GMT in winter (1) on road accidents (2) on activity patterns over the course of the day (3) on energy use (4) on electricity generation and price and (5) on other issues relating to clock time policy. This study of the evidence shows that remaining on GMT+1 all year would offer significant benefits throughout Great Britain, including Scotland, because the earlier timing of sunset on GMT results in more traffic accidents and higher, more costly, evening peaks in electricity consumption than would occur on GMT+1. Further benefits would result from GMT+2, which would better align daylight with clock based activity patterns over the day during the rest of the year.

No evidence in favour of imposing GMT in winter was found. The findings reported here are in the nature of worked examples that explain, given the assumptions made, why clock time on GMT has an adverse effect on electricity demand, on peak electricity costs and on emissions. Allowing for seasonal effects, from 2001 to 2006 a 2% increase in average daily electricity consumption is estimated to have occurred during GMT months, over and above the electricity consumption to be expected in GB if clock time had been on GMT+1. Reckoned cumulatively since the re-imposition of GMT in 1971, being on GMT+1 in winter could have supplied the population of Greater London with electricity for 2 years at current consumption rates.

When the price of electricity rises as a result of higher demand peaks (from early onset of dark under GMT), this higher price affects consumers in Scotland as it does those in England and Wales. Estimates showed an increase in electricity prices during GMT months of 5% over what would have occurred under GMT+1 because of higher peaks in demand .
These estimates suggest that emissions savings of 1.2 million tonnes CO_2 would have been achieved if GMT+1 had been implemented in winter in 2006. The cumulative extra carbon emissions released due to the imposition of GMT during winter months since 1971 can thus be estimated as in the order of 46.4 million tonnes. CO_2. Since carbon emissions exert a cumulative effect, this CO_2 will have built up over time in the atmosphere.

The impact of clock time on other issues is summarized in the following table.

Summary Table of issues related to clock change policy

	Current Evidence	Source of Evidence	Groups Supporting Change	Effect of moving the time regime forward
Road Accidents Associated medical costs to NHS	In GB, 450 serious injuries and 104 deaths annually could be prevented by GMT+1/GMT+2 clock time. GMT- induced injuries cause £200m per year costs to NHS. Cumulative costs since GMT reintroduced in 1971: £7b	Transport Research Lab, 1998 Hillman 1993	Royal Society for Prevention of Accidents Support change/ Association of Head Teachers support change	Favourable
Electricity demand and price	2% reduction in average daily wintertime electricity consumption from GMT+1 continuing in winter. Reduction of peak time electricity generation costs	Regression analysis based on National Grid data, Cambridge University, 2007	Privatized electricity firms not charged with conducting research on clock time and energy use.	Favourable
Crime & Security	Decreased crime & increased security	Policy Studies Institute, 1993	Age Concern support	Favourable
Health, Leisure & Wellbeing	Average of 55 min daily increase in accessible daylight	Policy Studies Institute, 1993	BMA support	Favourable
Tourism, Commerce & Industry	£1 billion boost from more opportunities for sightseeing / activities in the evening	Policy Studies Institute, 1993	Tourism Alliance support	Favourable
Trade and Finance	Improved conditions for trade with Europe	No studies found	CBI now favours change	Favourable effects can be inferred
Early morning workers	Issue of light for early morning workers	Construction industry findings	National Farmers Union now neutral	Unfavourable but working hours could be adjusted.
Population living in north	Darker morning in winter counterbalanced by more light during early evening – which is the peak period on roads and for energy use.	Accident impact studies Cost of electricity	Scottish MPs oppose change	Favourable evidence - has not been diffused.

There would be a favourable impact from a policy change to GMT+1 in winter on all dimensions shown, with the exception of the impact on early morning workers. However working hours could be altered for particular groups, as in Scandinavia.

We identify the cause of higher accidents under GMT: there is an early morning peak in accidents from 8.00 am to 9.00 am, but a higher and longer lasting accident peak occurs from 3.00 pm to 6.00 pm when activity rates are higher than in the morning. In Scotland, as in the rest of GB, earlier timing of sunrise and sunset under GMT shifts light to the morning, when traffic is lighter, at the cost of an hour's less light in the evening period when the traffic peak is heavier and longer than during the morning peak (p. 9). Clock time on GMT results in over a hundred unnecessary deaths on the road annually in GB, and over 40 deaths and serious injuries in Scotland. These tragedies entail massive costs for the NHS.

The evidence of the adverse effect of GMT on road accidents is not contested by the government. Therefore strong compensating effects would have to be shown to justify imposition of GMT. On the contrary, estimates using different methods consistently show GMT to have an adverse direction of effect on electricity use and costs. To obtain exact scientific data instead of estimates, we require evidence from an experimental period of clock time change. The available evidence is already more than sufficient to justify this policy change.

INTRODUCTION

"Evidence based policy" is the watchword today.[1] Since 1916 the aim of daylight saving has been to align clock time with the activity patterns of the population by putting clocks forward in summer. However the impact of setting the clocks back to Greenwich Mean Time after the end of British Summer Time is an institutional practice so well entrenched that it appears to be exempt from evidence-based policy making.[2] Among the most important benefits of the return to GMT in winter should be: (1) a reduction in traffic accidents; (2) a better alignment of activity patterns with solar time than alternative clock time regimes; (3) a reduction in generation costs and saving of energy. Yet these benefits have been assumed rather than investigated.

No systematic evidence has been produced and no research commissioned in support of the government's position. In what follows we begin by reviewing evidence neglected by policy makers and go on to undertake a new investigation of the impact of imposing GMT on electricity consumption, generation costs and carbon emissions to see if there is evidence in support of the return to clock time on GMT in winter.

Whether a move to double summer time (GMT +2) would be beneficial is a separate question for which less evidence is available since this time regime is not currently applied. However

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[1] www.defra.gov.uk/science/how/evidence.htm refers to the 1999 *Modernising Government* White Paper, which noted that Government "must produce policies that really deal with problems, that are forward-looking and shaped by evidence rather than a response to short-term pressures; that tackle causes not symptoms".

[2] There was awareness by 1919 that daylight saving should be applied in winter. *"Of course, we would save more coal probably if this daylight saving existed throughout the year."* a representative of the New York Daylight Saving Association pointed out in testimony to the US Congress (Downing 2005).

it can be inferred from the evidence that GMT+2 would offer benefits since it would improve the alignment of daylight with clock based activity patterns over the day.[3]

In the remainder of this paper we examine the evidence on the impact of returning to GMT in winter (1) on road accidents (2) the alignment of activity patterns with solar time (3) on energy use patterns (4) on generation costs and (5) other issues relating to clock time policy are examined.

Greenwich Mean Time (GMT); once an Institutional Innovation

Greenwich, near London, became the meridian at which longitude is defined to be zero degrees when it was selected as the global Prime Meridian in 1884 at an International Meridian Conference in Washington. Greenwich Mean Time became the standard for comparing time zones across the globe.[4] Greenwich Mean Time is so defined that solar noon (the point at which the sun is highest in the sky) occurs at midday in Greenwich, London. The original purpose of standardizing UK time on GMT was to give British mariners a method of navigation at sea. The first accurate marine timekeeper was built in 1759 and made it possible to use GMT to determine longitude by comparing solar time at sea to GMT. Institutional innovations tend to be long lived and so Greenwich Mean Time has proved to be as the default time regime for the UK, without systematic reassessment of its impact by policy makers.

UK Government Policy on Daylight Savings Time (DST)

British Summer Time was introduced in 1916 to save coal. During the Second World War GMT+1 was in use in the winter months and GMT+2 in summer, again to reduce fuel consumption. Further changes and attempted changes in clock time policy are listed in Table 1.

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[3] Further analysis is needed on gas consumption associated with GMT in the UK and on clock time issues arising in Northern Ireland.

[4] There is considerable pride in Britain in the Greenwich Meridian. The term Greenwich Mean Time could be retained by use of GMT+ 1 or GMT+2 as local terminology, with GMT as an absolute, scientific measurement.

1916	BST introduced
1941-47	A GMT+1/GMT+2 regime implemented (except for 1946)
1968-71	UK remains on BST all year
1981	Dates of clock changes synchronized with those of EU countries (UK remained one hour behind CET: on GMT in winter and GMT+1 in summer)
1994	"*Central European Time*" Bill [HL] introduced by Lord Viscount Mountgarret
1995	"*Western European Time*" Bill [HL] introduced by Lord Viscount Mountgarret
1995-96	"*British Time* (*Extra Daylight*)" Bill [HC] introduced by John Butterfill MP
2004	"*Lighter Evenings*" Bill [HC] introduced by Nigel Beard MP
2005	"*Lighter Evenings* (*Experimental*)" [HL] introduced by Lord Tanlaw
2006	"*Lighter Evenings* (*Experimental*)" [HC] introduced by Tim Yeo MP

Table 1: Legislation and Proposed Legislation on Clock Time in the UK.

An experiment was conducted in setting clock time an hour ahead of GMT from February 1968 to October 1971 in the UK. The motive was to improve business communications with Europe as, at this time, only Britain and Italy were not on GMT+1 all year among Western European countries. This experiment was terminated through an open vote in the House of Commons, when 366 Members of Parliament (to 81 in favour) voted against prolonging the experiment. This was despite road research laboratory evidence showing that road accidents had been reduced during the experiment and opinion poll findings that more people were in favour of the experiment than against it.[5] Many of the speakers questioned the statistics, quoting letters and anecdotal evidence from their constituents. Hansard records show that the main issues raised were morning road accidents involving school children and disruption to dairy farmers, construction, delivery and postal workers.

The position of the UK Government since this time has been to maintain the current time regime. An explanation of the position appears on the website of the Department for Business, Enterprise and Regulatory Reform:

"*Proposals have been made from time to time about changing the UK's time zone to Central European Time. However, any changes would need to have full regard to the effect on business and transport links with other countries, on health and safety issues such as road*

[5] House of Commons Hansard, 02nd Dec 1970 c.1332.

traffic accidents, and on social and community life. Although there could be some advantages, adoption of Central European Time in the UK would result in later sunrise in winter, affecting particularly outdoor workers and people in the north of England and Scotland. There are no current plans to change the UK's time zone."[6]

During the House of Lords debate on the 2006 "Lighter Evening's Bill", the government's position was that the current clock time regime is: "*a satisfactory compromise between those who prefer lighter mornings and those who prefer lighter evenings.*" [7] We revisit this policy position in the conclusions, after reviewing and analyzing the evidence.

1. Road Accidents under GMT

The timing of sunrise and sunset is relevant to road accidents because clock time has a greater effect on the pattern of activity on the roads than does the incidence of daylight; for example most people return from work between five and six p.m., whatever the timing of sunset. Reduced daylight reduces visibility and so provides less opportunity for drivers to react. Relatively few accidents occur due to sudden equipment failure which cannot be avoided. Accidents usually occur through human failure to react in time to a dangerous situation (Broughton, 1999).

To highlight the diurnal pattern of road accidents, we carried out a new analysis of the proportion of road accidents that occurred at different times of day in GB and in Scotland (Figure 1). The figures are consistent with more intense activity on the roads occurring over more hours in the late afternoon than during the early morning peak. More drivers are consequently at risk of accidents from early evening darkness than from early morning darkness. There are more pedestrians on the roads in the afternoon, including more children, who are at 75% greater risk of accident after school than before school (RoSPA 2006 & House of Commons Library 2007). The distribution of accidents by time of day reflects travel-to-work patterns, which do not show much seasonal variation.

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[6] http://www.dti.gov.uk/employment/bank-public-holidays/bst/page12528.html (accessed on 31st July 2007). This was confirmed in a private email communication from the responsible department summer 2007 which added: "*We are not convinced that a change to current arrangements would be in the best interests of the UK and the impact of darker mornings should not be underestimated*."

[7] House of Lords Hansard, 26th Jan 2006 c.1384.

Figure 1 shows the daily pattern of road accidents in GB and separately for Scotland, where the activity on the roads and hence of accidents by time of day is very similar to the rest of GB.

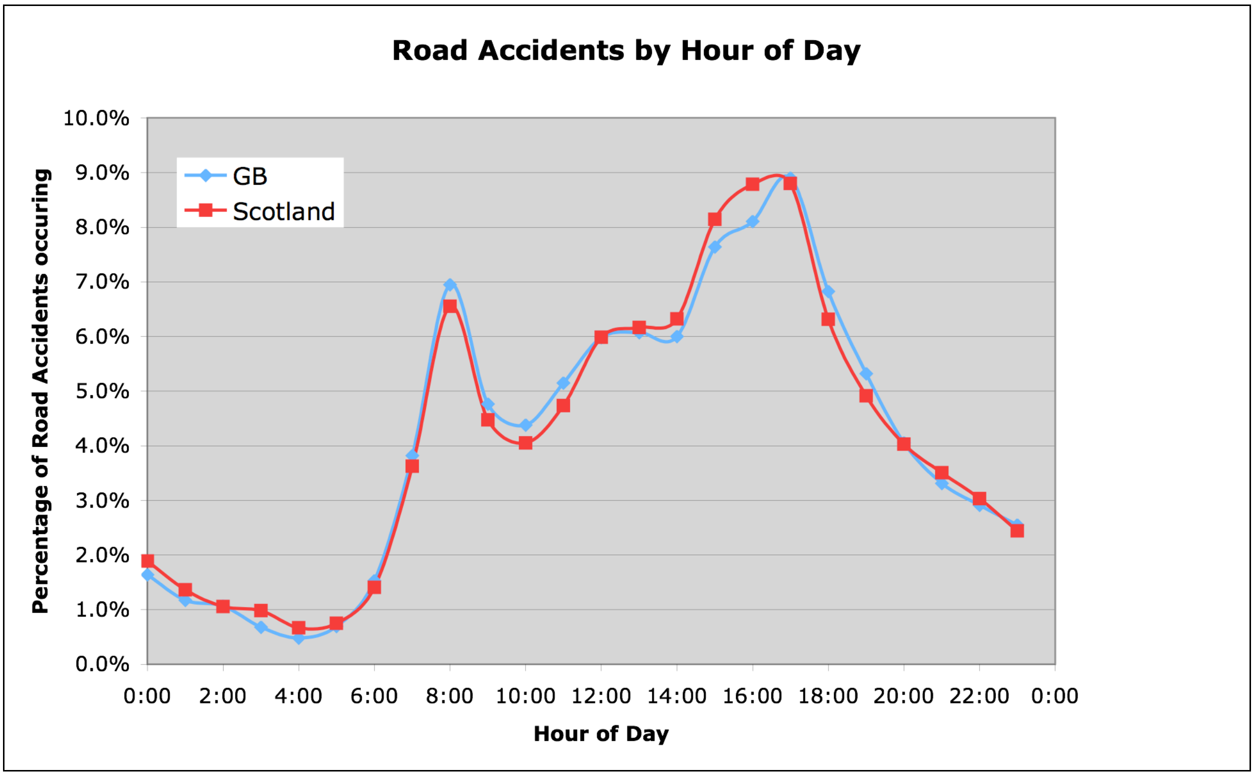

Figure 1: Percentage of Road Accidents Occurring by Hour of Day, GB and Scotland, (2001-6 averages).

There is an early morning peak in accidents from 8.00 am to 9.00 am, but a higher and longer lasting accident peak occurs from 3.00 pm to 6.00 pm. In Scotland, as in the rest of GB earlier timing of sunset under GMT results in the onset of dark during the period of the day when the traffic is heavier for longer than during the morning peak. The effect on accidents of a return to GMT in winter is therefore predictable and explains the consistent series of findings that road accidents are higher under GMT than GMT+1. To assess the impact of clock change, relevant data are the total of accidents morning and evening. It is misleading to focus on the one without the other.

Analysis of the impact on accidents of the 1968-71 Clock Time Experiment

The first study of the road accident savings achievable from a change in the time regime was carried out by the Transport Research Laboratory on the data from the 3-year GMT+1 all year experiment carried out from 1968-71 (Broughton & Stone, 1999). The report compared the winter of 1967-68 with the 2 trial winters of 1968-69 and 1969-70. It demonstrated that although there had been an increase in the number of killed and seriously injured of 900 persons in the morning period, there had been a far greater decrease of 3600 in the evening period, resulting in a net saving of 2700 people killed or seriously injured during the two winter periods when clock time was on GMT+1.

Because of changes in road use since 1971, analysis has been conducted on more recent data, modelling the effects of a simulated change in clock time policy. The most recent and in-depth study has been carried out by the Transport Research Laboratory in conjunction with University College London (Broughton & Stone, 1999). For this study, a database of accident statistics was prepared for several sets of years, the most recent being 1991-1994 which include the exact time of day as well as latitude and longitude of the accident location. This allowed the authors to correlate accident frequency with level of light. This correlation was then used to simulate the effects of a GMT+1/GMT+2 regime for the period 1991-1994. The results are shown in Table 2.

	Killed	**Seriously Injured**	**Injured**
Morning	-39	-265	-601
Evening	143	604	1717
Net reduction	104	339	1116
Reduction as % of total	**2.5%**	**0.7%**	**0.4%**

Table 2: Net annual reduction in accidents in GB for the period 1991-1994 had a GMT+1/GMT+2 clock time regime been implemented in place of GMT/GMT+1.

Net reduction in fatalities of 104 people per year and of 339 serious injuries were estimated by this analysis. A GMT+1/GMT+2 regime would cause a small decrease in accidents, but the severity of accidents overall would decrease by a much greater extent.

If a GMT+1/GMT+2 regime had been adopted during the 1990s in Scotland, there would have been an annual reduction on Scottish roads of all casualties of 57 persons per year and a reduction of killed and seriously injured persons of 41 persons per year, according to the Transport Research Laboratory's study (Broughton, 1998), the most comprehensive inquiry yet conducted (Table 3).

	Killed and Seriously Injured	All casualties
Morning	-30	-44
Evening	71	101
Net reduction	41	57
Reduction as % of total	**0.74**	**0.24**

Table 3: The Estimated Effect of a GMT+1/GMT+2 regime in Scotland in the 1990s Transport Research Laboratory (Broughton and Stone, 1998).

To the incalculable human costs of traffic accidents must be added costs to the National Health Service and related infrastructures. Over 35 years of accidents during darker than necessary early evenings, the National Health System may have accumulated over £7b in costs. In a comprehensive report on the impact of GMT, Hillman estimated in 1993 that the reduction in expenses to the National Health System of GMT+1/GMT+2 would be in the region of £200 million a year (Hillman, 1993).

Why has British evidence, consistent with international findings, been disregarded?[8] Psychologists have found that people rely on one prominent piece of information when making decisions and fail to correct this in the light of more complete evidence (Kahneman, 2002). The deaths of schoolchildren on the way to school during the darker winter mornings were well publicized by the press and attributed to the GMT+1 experiment.[9] However, comprehensive findings on the much greater reduction in afternoon deaths on GMT+1 did not make the news and have not been retained in folk memory.

[8] To compare these results with international findings, a recent paper (Sood & Ghosh, 2007) analyzed United States fatal road accident statistics for the period 1976-2003 using a regression model. The results showed that there was an 8-11% fall in fatal crashes involving pedestrians and a 6-10% fall in fatal crashes for vehicular occupants in the weeks after the spring clock change caused by the shift onto DST.

[9] It is now easier to set street lights to come on again in the morning than it was in the period 1968-1971 before switching was fully computerized. Today children are at greater risk from accidents after than before school (RoSPA 2005).

2. Activity Patterns and Clock Time

Road accident statistics are one indicator of activity patterns over the course of the day. The latter are the most telling evidence for clock time policy since the basic rationale is to align

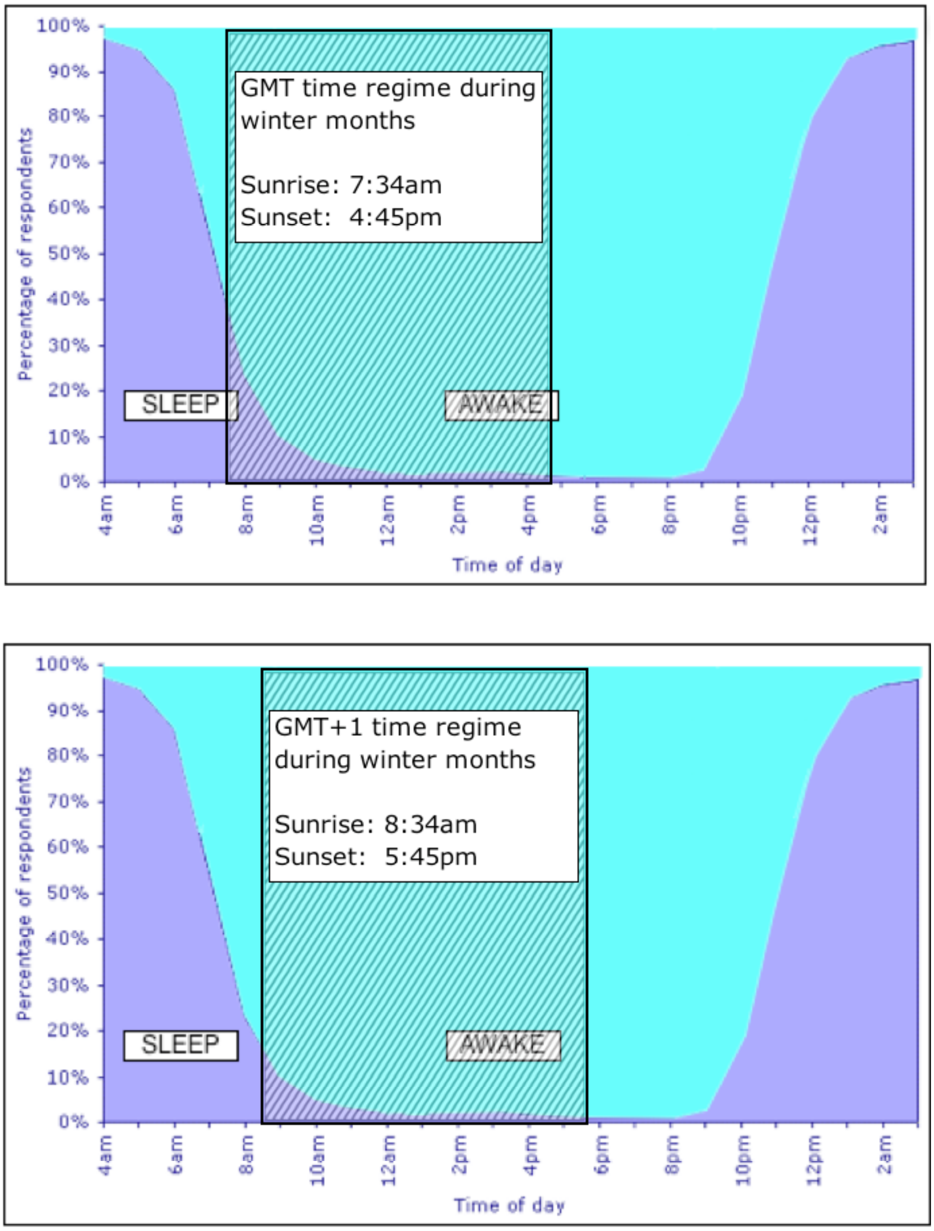

Figure 2: Daily Activity Patterns and hours of sunlight during winter months showing hours of daylight (shaded) on GMT and on GMT+1
(For Birmingham; adapted from National Office of Statistics).

clock time with activity over the day. The time at which urban people wake in the morning is influenced to a greater extent by clock time than by the timing of sunrise. Figure 2 shows weekday sleep patterns in the UK in winter. Overlaid on the diagrams are typical hours of sunlight during the winter months. Currently under GMT, around 35% of the population are asleep when the sun rises in winter. Shifting to GMT+1 in winter would time sunset to occur when under 20% of people are asleep.

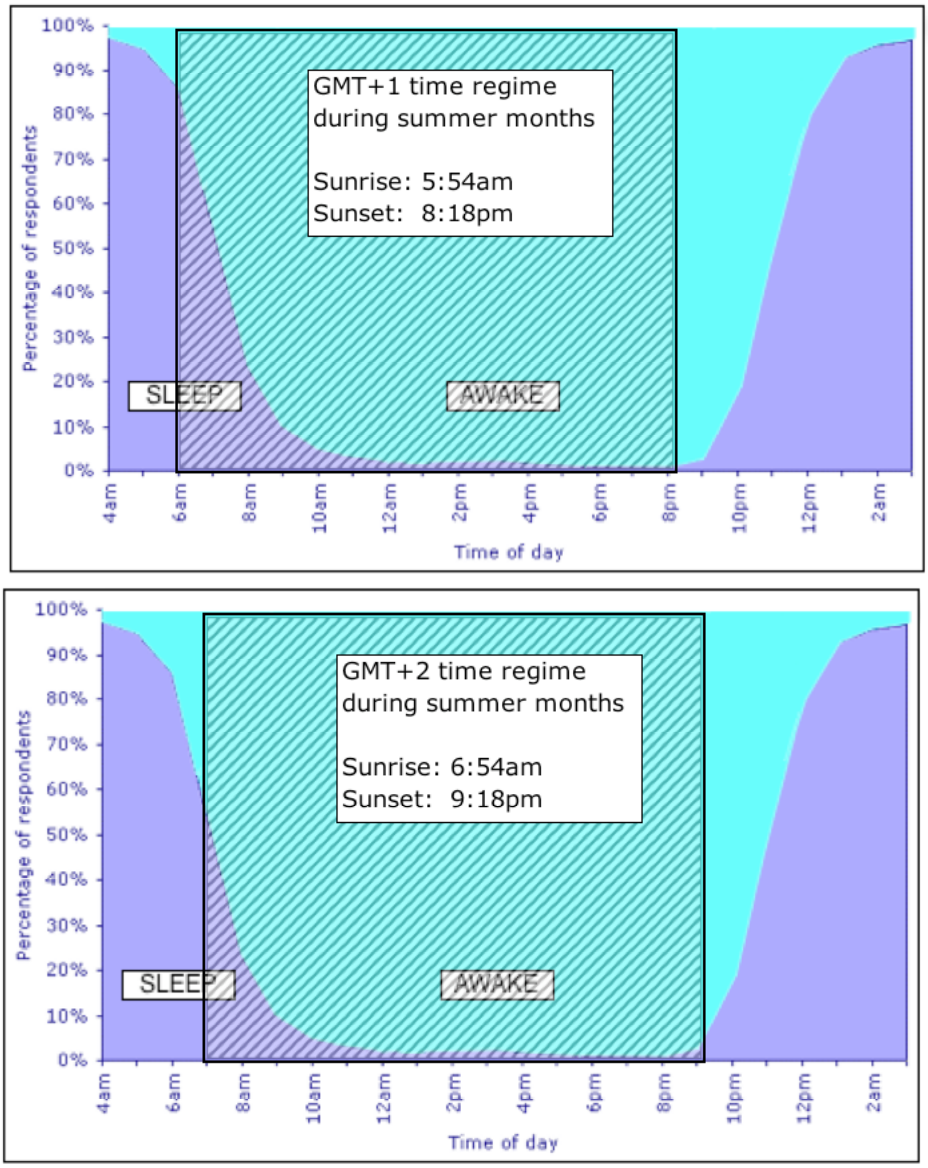

Figure 3: Daily Activity Patterns and hours of sunlight during summer months for Birmingham showing hours of daylight (shaded) on GMT+1 and GMT+2.
(Adapted from National Office of Statistics).

Very few jobs have different working hours during the winter and summer months. From the figure showing the period of sunlight in summer under GMT+1 it can be seen that under

GMT+1 on average over 80% of the population are asleep at sunrise, while several hours of energy-consuming activity follow sunset.

3. Demand for Electricity and the Impact of GMT

Is there evidence on energy consumption and costs to support the case for GMT in winter? Our literature review yielded no research in the public domain on the impact of clock time on energy consumption and costs in the UK. It was necessary to carry out a new analysis of primary data.

Annual trends in temperature and daylight and the dates of clock changes

In analyzing the impact of clock time on energy consumption we begin by considering the main determinants of demand for energy: temperature and hours of daylight. At low temperatures, demand for electricity in the UK decreases by approximately 350 MW for each degree Celsius of increase in temperature.[10] Temperature is subject to annual fluctuations around the seasonal trend.

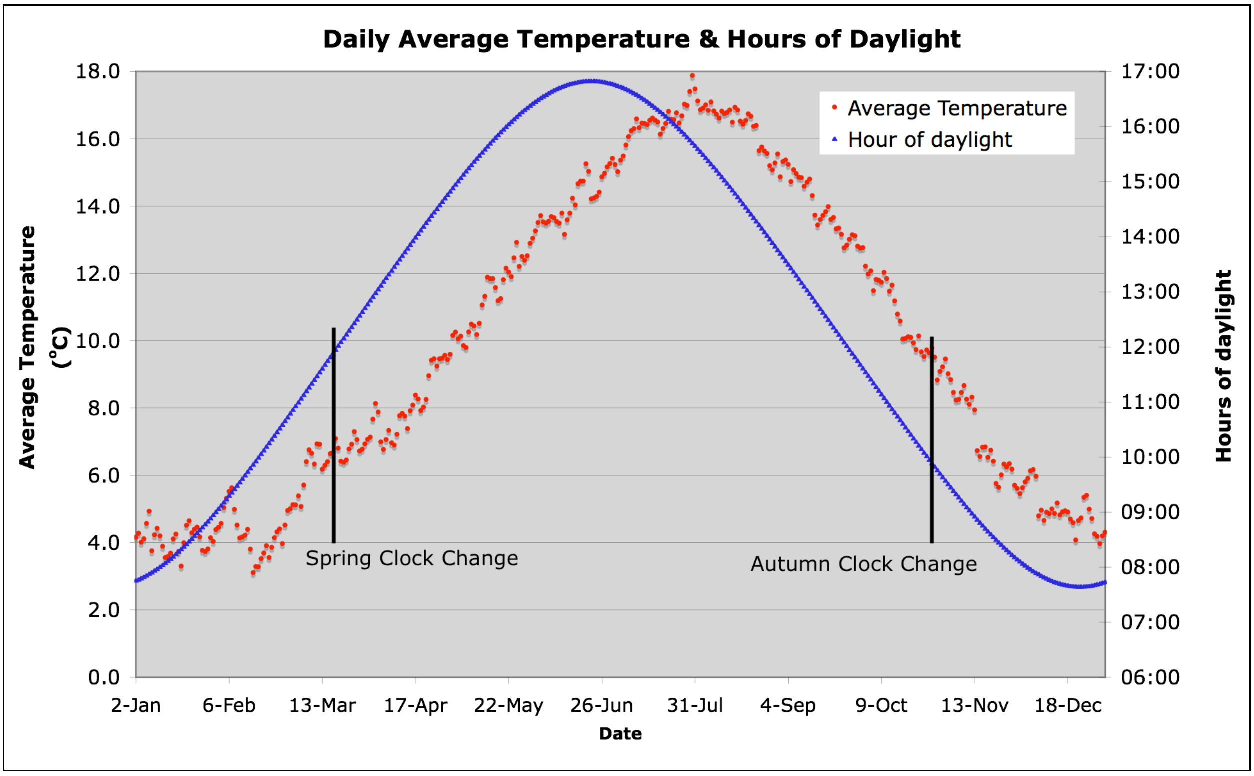

Figure 4: Annual Change in temperature and hours of daylight.

[10] Thus over 24 hours one degree of temperature rise would result in 350MW x 24 MWhs less electricity being consumed = 8400 MW. This is however a rule of thumb which cannot be used for precise estimates.

Figure 4 shows the annual change in temperature (left axis) and daylight hours (right axis).[11] From the timing of clock changes marked in Figure 4, we see that the seven months of British Summer Time are not synchronized either with hours of daylight or with seasonal temperature. The clock is set back to GMT two months before the shortest day of the year (21/22 Dec) but remains on GMT until three months after the shortest day. The spring clock change occurs four months before the hottest day (end July), but the autumn clock change occurs three months after this date. This results in the spring clock change occurring at a temperature around 2°C cooler (7°C) than the autumn clock change (9°C). There is more daylight at the time of the spring clock change, roughly 13 hours of daylight, compared with 11 hours, at the time of the autumn clock change. These asymmetries are the result of historical accidents in the timing of clock change, and have no rationale based in evidence.

Electricity Analysis: Annual Demand Trends

Average Daily Demand Trend

The annual trend in daily average electricity demand is shown in Figure 5.

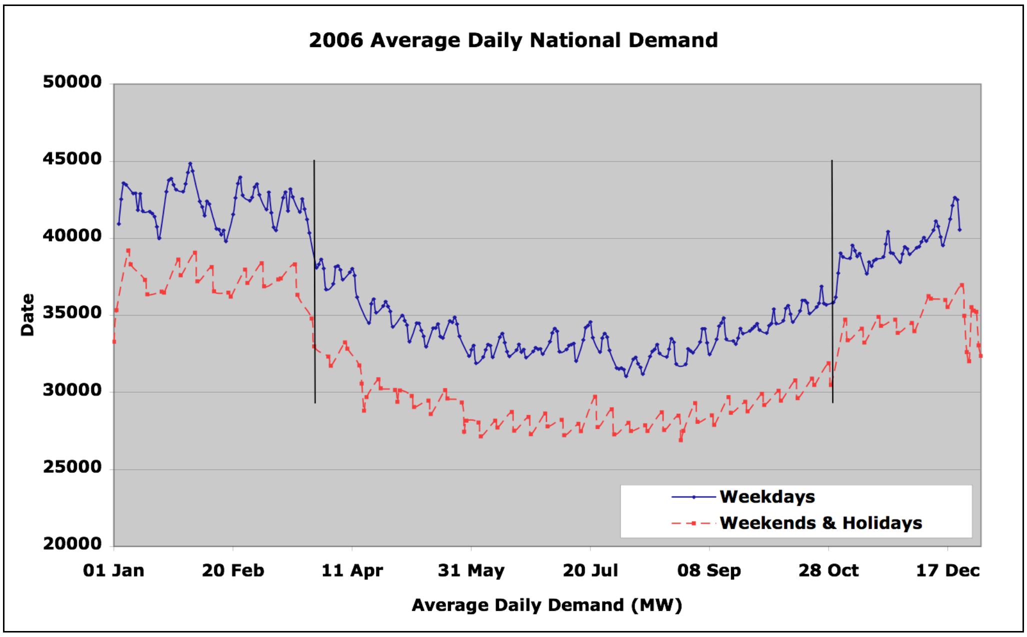

Figure 5: Average Daily Electricity Demand for 2006.

[11] The average temperature data in Figure 4 is a 20 year average of the central England temperature index. The hours of daylight are plotted for Birmingham as a central location in the UK. http://badc.nerc.ac.uk/data/cet/ (accessed 02 08 07).

The solid lines on the graph indicate the spring and autumn clock changes. There appears to be a stepped drop in demand at around the clock change at the end of March in the illustrative data for 2006 shown in Figure 5. But a small percentage change in electricity consumption in response to clock changes might well be swamped by fluctuations about the seasonal trend. Similarly, at the autumn clock change, demand increases markedly above the existing trend. Regression analysis can be used to control for the effects of temperature and hours of light and isolate the impact of changing clock time on electricity consumption.

Regression Analysis of GB Demand with Temperature and Daylight[12]

Since a regression equation can provide estimates of one or more unknown regression coefficients which link dependent and independent variables, regression analysis can be used to generate equations showing how GMT, temperature and hours of daylight are linked to daily power consumption. The data were provided by the National Grid Company for the period 2001 to 2006. To estimate the effects of moving back to GMT in winter, a regression analysis was performed with average daily electricity consumption data as the dependent variable,. The variable and units used in the following regressions are as follows:

- Daily Electricity Consumption in Megawatts-hours
- Temperature in degrees Celsius
- HOD (Hours of Daylight), expressed as the fraction of the total day during which it is light
- Weekend, expressed as a binary variable, set at 0 during the week and 1 for weekends; holidays are assumed to have weekend demand levels
- GMT, expressed also a binary variable, set to 1 during GMT and 0 during GMT+1.

The first stage of the calculation was to perform a regression analysis on temperature, hours of daylight and weekend effects without including GMT. This resulted in the equation:

Daily Consumption = 1266024 - 10925*Temperature - 348960*HOD - 141763*Weekend

This equation had a high coefficient of determination of 0.90, showing that 90% of the annual variance in demand can be described by temperature, hours of daylight and weekend/holiday.

[12] Prof. Mark Franklin of the European University Institute worked with the authors on the regression analyses. Professor Franklin produced the regression analysis contribution to the original version of SPSS.

The residual demand (the portion of the demand not modeled by the above equation), is calculated as:

$$\text{Residual Demand} = \text{Actual Demand} - \text{Predicted Demand}$$

The residual demand was then regressed with GMT to see what portion of residual demand can be attributed to changing to GMT from GMT+1. This resulted in the equation:

$$\text{Residual Demand} = 18942*\text{GMT} - 7807$$

This implies that the daily consumption is 18,942 MWh higher on GMT compared to GMT+1, when the effects of daylight and temperature have been allowed for. This equates to 135,594 MWh extra consumption per week on a GMT time regime compared to GMT+1. The regression analysis finds that the increase in demand associated with GMT, controlling for effects of temperature and daylight, amounts to 2.2% of average daily consumption. In other words, there could be an average saving of 2.2% of daily consumption by remaining on GMT+1 all winter. The method is conservative in that co-linearity between temperature, hours of daylight and GMT are captured in the temperature and hours of daylight variables and not distributed also to GMT.

In order to confirm that other annual variations excluded from the equations do not compromise the results, a regression was performed using only the 2 weeks either side of the clock changes for the years 2001-2006. For data from this time of year, the effect of the clock change variable should be large compared to that of any variations in other excluded parameters such as cloud cover. The result of the regression shows:

$$\text{Residual Demand} = 27465*\text{GMT} - 13733$$

For the analysis using data from clock change weeks, the coefficient of determination is 0.15. It can be seen that daily consumption when clock time is on GMT is 27,465 MWh per day higher than if clock time were on GMT+1 during these weeks. This is not out of line with the figure of 18,492 MWh obtained using the data for the full year and so indicates that other variables such as cloud cover do not significantly influence the results. The difference between the analysis using whole year data and the result for the four clock change weeks is explained by seasonal differences. In mid-winter, the hours of daylight are so short that moving their position by an hour does not make as much difference to peak time light availability as in autumn and spring.

To work out the effect of putting the clock forward by introducing GMT+2 on electricity consumption (as compared with GMT+1 in summer) we need actual data from policy change to GMT+2. But it can be inferred directly from activity patterns that there would be major savings from going onto GMT+2 in summer. This would shift the clock ahead by hour - and so until the time when more of the population are awake; it would delay sunset at a time of day when activity is at its most intensive.[13]

No evidence has been found that a return to GMT in winter contributes to saving electricity. An alternative method comparing electricity demand in the weeks before and after the clock change were used to explain the findings of the regression analysis. This calculation is reported in Appendix D. This method provides a check on orders of in the regression analysis, but is not able to control systematically for temperature fluctuations from year to year. From the estimates using this method, we find an increase of somewhere between 1% and 3% of daily electricity consumption results from clock time being on GMT, with seasonal variations. The calculations reveal consistent seasonal differences in the effect of clock time policy. In the next section we investigate the period over which consumption increases persist under GMT.

Electricity Analysis: Peak Demand Trends

Thus far we have assessed average daily demand on different clock time regimes to see whether there are benefits from returning to GMT in winter. The effects identified result in part from uneven demand for electricity over the course of the day.

We can identify the effect of the clock change on the profile of daily demand for electricity using the following method. A typical weekday demand profile from a day before and after

[13] An hour of electricity consumption extends for 7% of the period during which electricity usage is high (7am to 9 pm). The change in demand for lighting on GMT+2 could be calculated as the part of that 7% figure representing demand for artificial lighting, taking into account any morning consumption increase caused by the clock shift (i.e. the difference between one hour's demand for electrical lighting morning and evening). A thought experiment indicates that at times of year when consumption is much higher in the evening than in the early morning, the savings from GMT+2 would be no less than the 2% daily reduction in electricity demand shown by the regression analysis as resulting from a change to GMT+1 in winter.

the spring and autumn clock change for 2006 is plotted in Figures 6 & 7 below. To enable us to isolate the effect of GMT on the peaks in demand, the data for the week after the clock change were normalized by assuming that demand at midday on both days was independent of any clock change effect. The demand for the week after was scaled, so that the demand at 12.00 matched the week before. This method (proposed by Chris Rogers of the National Grid Co.) does not claim to represent absolute values, but is useful for comparing the shape of the demand profile from one week to the next. It shows how peaks increase when the clock shifts to GMT in autumn and lessen with the return to GMT+1 for the spring clock change.

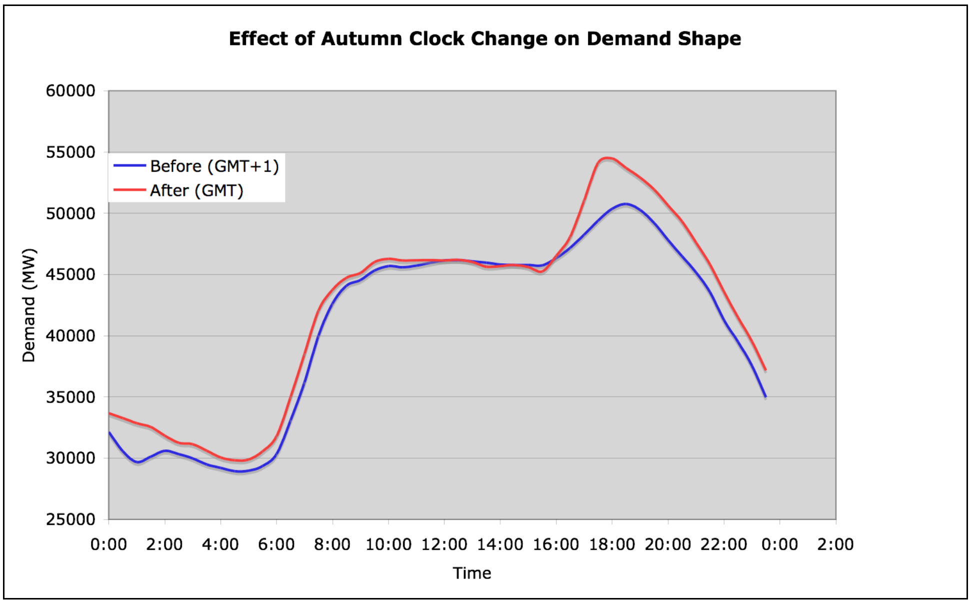

Figure 6: Effect of autumn clock change on the demand profile, 2006.

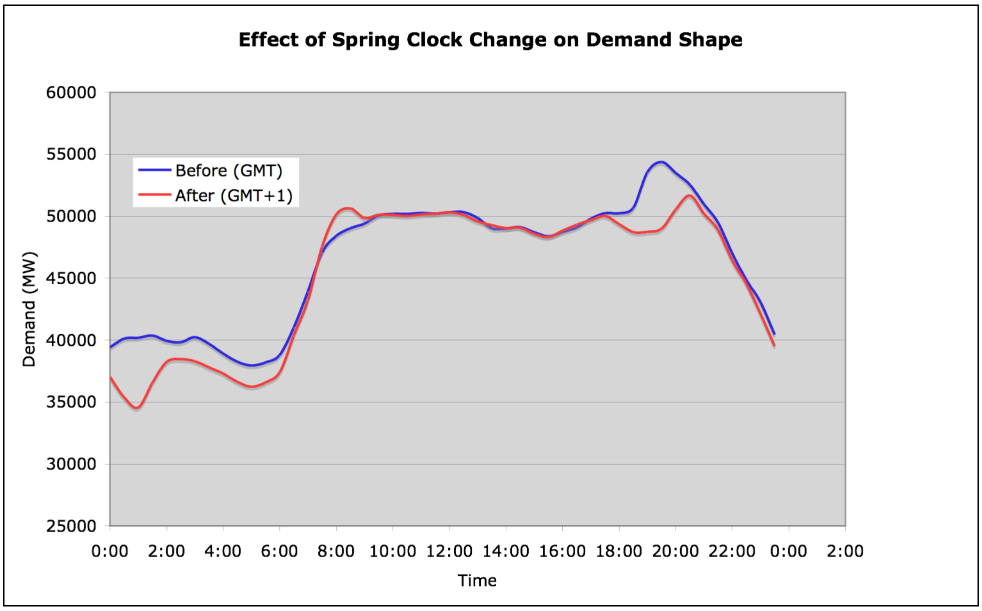

Figure 7: Effect of spring clock change on the demand profile, 2006.

The effects of autumn and spring clock changes (Figures 6 &7) are not symmetrical because of lower temperature and more light in March. The autumn clock change takes place just two months before the shortest day when demand is greater and the scope for separating return from work and onset of darkness peaks is less than in spring, when hours of light are longer.

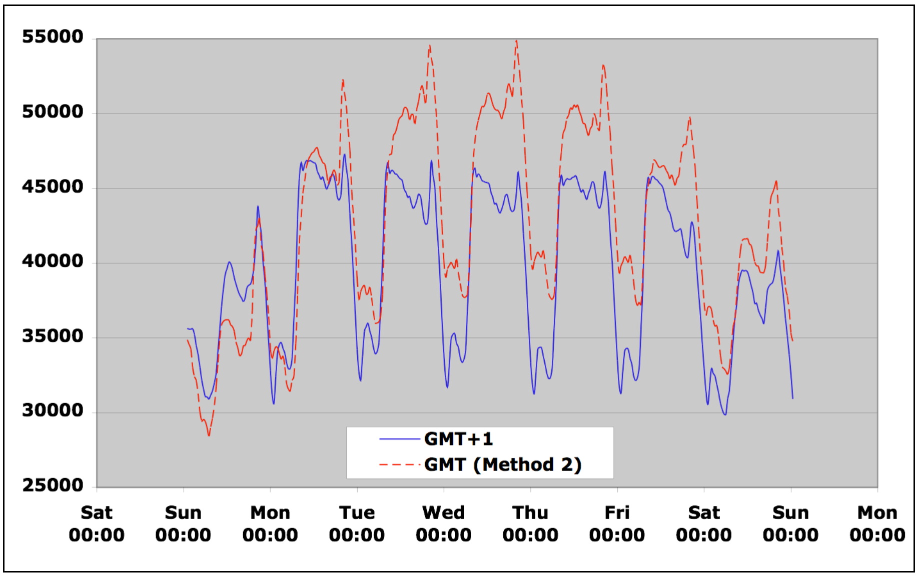

Figure 8: Electricity Consumption Compared, (under Actual GMT+1 and Assuming Continued GMT) over the Weeks of Spring 2004 clock change (Appendix D).

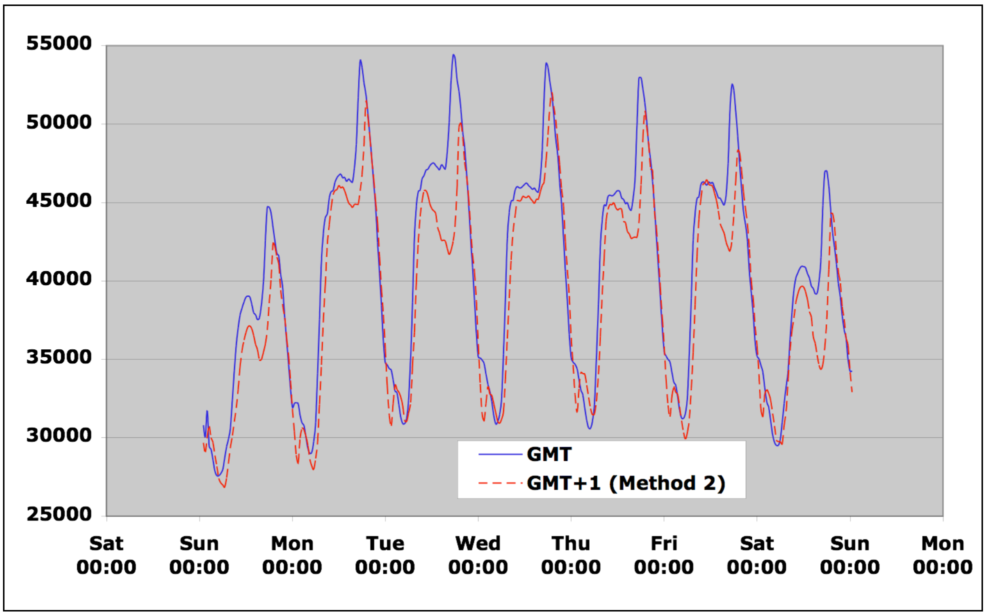

Figure 9: Electricity Consumption Compared (under actual GMT and Assuming continued GMT+1) over the Weeks of the Autumn 2003 Clock Change (Appendix D)

Figure 8 and 9 are based on calculations similar to those shown in Appendix D. In autumn 2003, shown in Figure 9, there was a seasonal rise in temperature in the week after the clock change that reduced demand for heating, and the higher peaks due to less evening light on GMT are thereby clearly revealed. The electricity savings from the return to GMT+1 effect in spring is much greater than maintaining GMT+1 in autumn would be. Nevertheless, the latter is undesirable because of adverse effects of earlier sunset on accidents during dark rush hours. Moreover, we see below that the generation costs of discontinuing GMT+1 in autumn are very considerable because of the knock-on effects on price of the high peaks in demand caused by clock time on GMT.

In general, severe winter peaking occurs when the period of intensive electricity usage and the onset of demand for lighting coincide because of early darkness. For how long a period of time does severe winter peaking continue as a result of the imposition of GMT? We found from calendar analysis that there are 34 days during which sunset in London is timed when clock time is on GMT to coincide with the daily period of maximum energy demand (which extends from around 16.00 hours to around 18.30 hours). For all of these 34 days, GMT+1 would delay sunset until after the period of peak energy demand, so reducing demand peaks.

4. Generation Costs under the GMT Regime

The aim of the analysis that follows was to examine how additional demand for electricity caused by GMT in winter translates into higher electricity prices, given the uneven profile of daily demand. It can be inferred from the use of reserve power to cover peak demand that high peaks in demand will map onto still higher peaks in generation costs.

An estimate of the increased cost of generating electricity caused by increased peaking in demand is based on market electricity price data. Since direct comparisons of electricity prices from one week to the next do not take into account fluctuations in seasonal variables that affect demand (especially hours of daylight and temperature), regression analysis is needed to control for effects other than the change in clock time.

The independent variables are hours of daylight (HOD), temperature and whether or not the day was a weekend/holiday (see p.14). Electricity prices from the period 27-Jan-2003 to 31-Dec-06, from publicly available market data, are the dependent variable. The regression equation is:

Price(£/MWh) = -5.767*weekend - 6.81*HOD - 0.74*Temp + 47.98

Residual = 1.88*GMT - 0.75

Allowing for the effect of weekends and holidays, hours of daylight (HOD) and temperature, this shows the price was higher by £1.88 on GMT than it would have been on GMT+1 during winter months from Jan 2003 to Dec 2006. The increase in electricity price associated with remaining on GMT in winter represents 4.7% of the average winter time price of £40.31 This is a conservative estimate as co-linearity between the independent variables is totally attributed to hours of daylight and temperature instead of being distributed also to GMT..

The variance in the dependent variable (price of electricity) is likely to be affected as levels of consumption alter (heteroscedasticity), so we go on to examine the reasons for generation cost variations and show that these relate to a considerable extent to patterns of electricity usage over the day, patterns that are affected by sunrise and sunset at an earlier clock time.

Factors affecting market electricity prices

Market price data under the current auction system fluctuates continually by hour and by day, depending as it does not only on seasonal and factors but on the interaction between traders. By averaging over five years, we found a smoother trend underlying the fluctuations in pricing from hour to hour and day to day. This trend reveals the very considerable generation costs caused by severe peaks in demand. Generation costs of peaks are proportionately much greater than the absolute increase in demand under GMT as opposed to GMT+1.

Electricity price data for the period immediately before and after the clock change date were prepared for the last 3 years for both spring and autumn clock changes. For each daily 30 minute time window (00:00-00:30, 00:30-01:00 … etc), the average for each of the 7 days, for each of the 3 years was calculated. Thus each point on the graph is an average of 21 points, allowing for market fluctuations to be smoothed and providing a clearer picture of the underlying trend in the electricity prices before and after the clock change.

The spike in electricity price illustrated by the October clock change in 2006 (Figure 10) shows that although the change in demand peaks (in the weeks before and after the clock change) are usually much smaller in the autumn than those in March, there can be a significant increase in the costs of electricity after the October clock change.

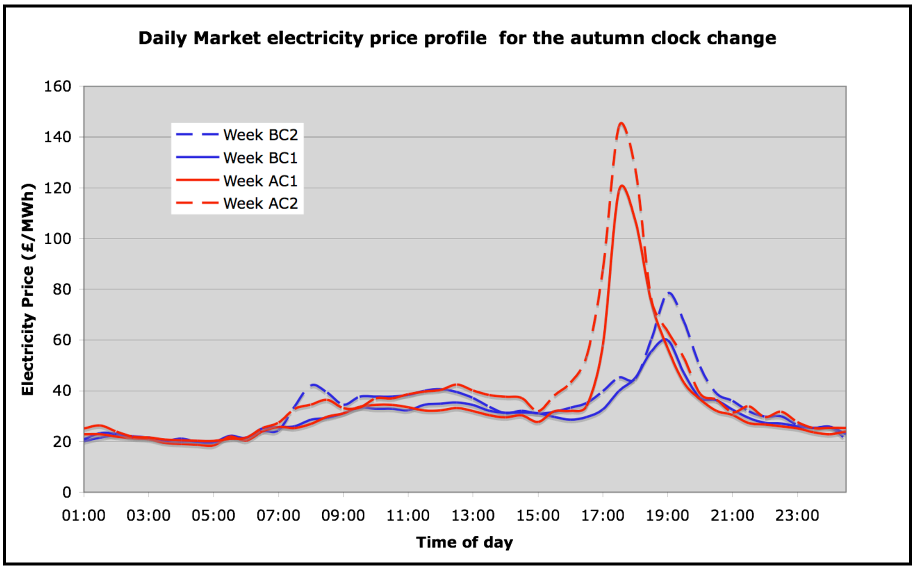

Figure 10: Average daily electricity price profile during the autumn clock change, 2004-2006 average. **(BC: before the clock change AC: after the clock change).**

We turn now to explore the way in which price fluctuations are affected by recourse to reserve power in generating electricity.

Generation costs and reserve power requirements

The reason why sharp peaks in demand create massive knock-on effects for generation costs is that they require recourse to the nation's reserve power. In order to meet the higher and more prolonged evening peak associated with GMT, less efficient plant (such as oil powered generation and pumped storage) have to be called on to generate electricity to meet the peak. Even when the extra generation capacity is only required for a short period, capital costs must be paid and equipment must be maintained, heated up and cooled down. A relatively minor increase in electricity demand at a time of peak consumption will give rise to a much more substantial generation cost. This explains why there is a marked price profile change at the time of the autumn clock change even though the change in evening peaking is lower than in spring.

Additional generating capacity needs to be bought online to deal with peaks and taken offline to deal with demand reductions. This must be dynamically balanced for all times of day by the electricity grid system operator (the National Grid Company). A steady demand profile is more manageable and requires less start-up and shutdown of generating capacity. As can be seen from the following table, power plants cannot simply be switched on and off to deal with peaks in demand. Some plants require most of day to become fully functional after they are turned on.

Generation Type	Response time
Pumped Storage	10 seconds
Gas Turbines	2 minutes
Combined Cycle Gas Turbine	6 hours
Oil Fired	8 hours
Small Coal	12 hours
Large Coal	24 hours
Nuclear	48 hours

Table 4: Typical Response Times of various forms of Power Generation (National Grid Company, 2007).

The different response times of power plants gives rise to the electricity generation mix depicted in Figure 11 below. This shows the level of power generated in Gigawatts (thousands of MWs) on the vertical axis and, on the horizontal axis, the duration of that level of power generation in hours over the day. The area under the curve measures electricity consumed in MW hours. Nuclear and coal typically supply base-load power because of their long response times; other forms of energy are called on to deal with peaks in demand.

Uneven demand associated with high peaks makes forecasting more difficult for the system operator. It may be necessary to call into operation reserve power, which is not subsequently required because of forecasting uncertainties. Even if that capacity is not actually put to use, start up and shutdown costs are incurred.

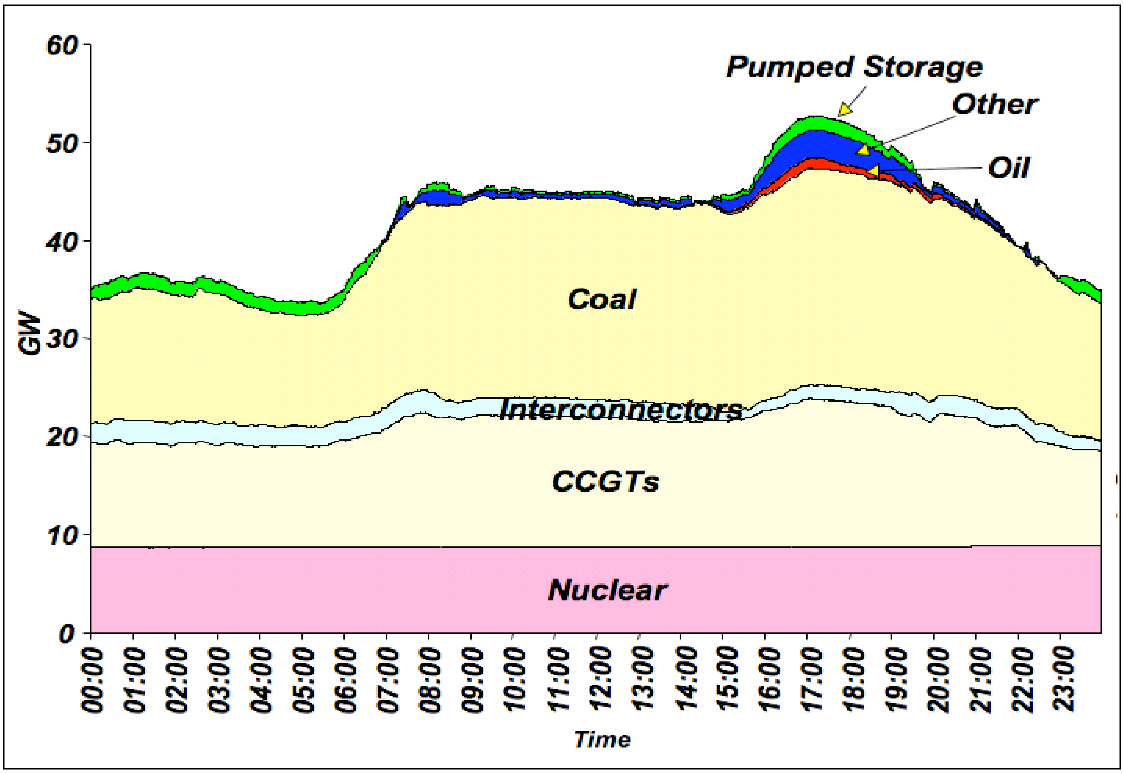

Figure 11: Generation source for a typical daily demand profile. *Courtesy of NGC 2007* **(CCGT: Combined Cycle Gas Turbines).**

The regression analysis estimated that the impact of GMT was to increase average daily electricity consumption by around 2% during months on GMT, but clearly any such effects would be greater or less at some times of year than this average (table 9 below). If, as a result of clock time changes, most of the increase in average daily consumption is concentrated during the evening hump in demand, this would require that expensive reserve power be called upon and be heated up over the course of the day, resulting in a much greater increase in generation costs.

Although market prices are only directly applicable to electricity distributors and suppliers, the impact of the market price of electricity is felt throughout the system when the imposition of GMT in winter months raises consumer electricity bills. As the price of electricity is the same over the whole of GB, if the price rises as a result of GMT related demand peaks, this feeds through to consumers in Scotland no less than to those in England and Wales.[14]

[14] BETTA introduced a single wholesale electricity market for the whole of GB on 1st April 2005: http://www.dti.gov.uk/energy/markets/electricity-markets/betta/page30130.html

Summary of Estimates

All estimates reflect assumptions made and data availability. A *consistently unfavourable direction* in the effect on energy demand and price of applying GMT in winter is found by the different methods and estimates reported here and it is the direction of change that has policy importance not the specific estimates, which are provided as worked examples of the logic of calculating clock time policy impact.

Regression analysis, controlling for the effect of seasonal factors on demand, allowed the effect of clock time on GMT to be estimated as an increase in 2% of annual daily electricity consumption. There are seasonal differences: regression analysis of the effect during the weeks of the clock changes suggested the higher figure of 3% daily electricity saving from a change in clock time during these weeks.

We checked the regression using a more conservative weekly trend method (Appendix D) to identify differences in consumption over the clock change weeks. These conservative estimates supported the order of magnitude of the regression analysis, yielding a figure showing that between 1% and 2% of daily electricity consumption could be saved if clock time were on GMT+1 at this time.

When electricity demand exceeds average usage this results in a still higher increase in generation costs. Regression analysis controlling for seasonal and other factors indicated that putting the clock back to GMT could be resulting in an increase of at least 5% in daily electricity prices over the months concerned.

To obtain precise data we require a period of clock time change. Despite and because of uncertainties in estimates of the impact of clock time on electricity use and cost, logic and evidence call for policy change on the basis of the precautionary principle.

Evidence on Other Issues affected by Clock Time Policy

Beyond electricity consumption and road accidents, a number of other important issues arise in connection with the return to GMT in winter. Table 6 summarises key issues and evidence on the effect of moving the time regime forward to GMT+1/GMT+2 for each issue.

Table 6 Summary of Impact of GMT

	Evidence and Argument	**Source of Evidence**	**Groups involved**	**Effect of moving the time regime forward**
Road Accidents Associated medical costs to NHS	In GB 450 serious injuries 104 deaths annually could be prevented by GMT+1/GMT+2 GMT imposes £200m+ per year injury costs to NHS. Cumulative costs since GMT reintroduced in 1971: £7b	Transport Research Lab, 1998 Hillman 1993	Royal Society for Prevention of Accidents support/ Association of Head Teachers support	Favourable
Electricity & Fuel Consumption	2% + reduction in average daily wintertime electricity consumption from change to GMT+1 in winter and reduction of over £200 million annually on electricity generation	Regression analysis Cambridge University, 2007	Privatized electricity firms must remain neutral. National Grid supports change.	Favourable
Crime & Security	Decreased crime & increased security	Policy Studies Institute, 1993	Age Concern support	Favourable
Health, Leisure & Wellbeing	Average of 55 min daily increase in accessible daylight	Policy Studies Institute, 1993	BMA support	Favourable
Tourism, Commerce & Industry	£1 billion boost due to more opportunities for sightseeing / activities in the evening	Policy Studies Institute, 1993	Tourism Alliance support	Favourable
Trade and Finance	Enhanced trade with Europe	No studies identified	CBI members favour change	Favourable
Early morning workers	Issue of light for early morning workers	Construction industry findings	National Farmers Union now neutral	Unfavour-able but working hours could be adjusted.
Population living in north	Darker morning in winter (10am sunrise - but counterbalanced by more light at peak evening period)	Accident impact studies	Scottish MPs oppose change	Public education campaign needed to diffuse evidence

Harmonization with Europe

Since 1971 there has been little activity by business or financial interest groups in favour of full harmonization of clock time with European Union countries. Groups opposed to such harmonization have been more vocal. The EU is the major trading partner of the UK; hence there are strong arguments for a move directly GMT+1 in winter and GMT+2, the clock time of most other EU countries. Since 1971, the only synchronization with EU countries has been the 1981 alignment of the dates of clock change throughout the European Union. This form of harmonization has imposed costs on the UK, since it prolonged the period of GMT. A move GMT+1 all year might be more feasible politically, since the clock change itself is unpopular and GMT+1 all year might be more acceptable to opponents of moving onto Central European Time.

Evidence-Based Policy and Advice

Evidence based policy calls for comprehensive evidence, evaluated and disseminated in a balanced way. Opinion on this subject is often based on incomplete assessment of the facts. For example, a columnist in the *Daily Telegraph* wrote: “The Royal Society for the Prevention of Accidents claims that the adoption of single-double summer time would result in 100 fewer road deaths; yet my recollection of the last experiment is that it resulted in more fatalities among children going to school.[15] This is an example of a judgment unrevised as more complete evidence comes to light, the error known by psychologists as ‘anchoring bias’ (Kahneman 2002). It is now recognized that it is overall accidents to children, not those in the morning only, that need to be taken into account when assessing the impact of clock time policy. The extensive evidence that accidents overall would be reduced by GMT+1 in winter has been overlooked.

Another example of use of incomplete evidence to draw invalid conclusions relates to the weight the UK government has placed behind the Portuguese experimental move to a GMT+1/GMT+2 regime from 1992-96 (Appendix C). The Portuguese case was presented as evidence of the undesirability of an experiment in the UK and was quoted extensively during the second reading of the “*Lighter Evenings (Experiment)*“ Bill of 2006. [16] However Portugal already enjoys an hour more light in the evenings on GMT than does the UK, through being

[15] *Daily Telegraph* 22/01/2007, Philip Johnston.
[16] House of Lords Hansard, 24th Mar 2006 c.479.

located so much further south. Thus it does not require a clock change for Portugal to achieve the benefits that GMT +1 in winter would offer the UK (Appendix C).

The government is in a unique position to commission research and provide public education campaigns to change behaviour that has unnecessary costs. The Government departments, have not produced any systematic research findings in the public domain in the case of clock change policy. At no time was electricity consumption data from the 1968-71 experiment analyzed. The Secretary of State for Trade and Industry responding in 2004 to questions in the House of Commons stated: "*The Government [has] not undertaken any research specifically addressing the economic or safety impacts of the biannual time change, other than as part of the consultation document published in June 1989.*"[17]

The National Grid Company forecasting team has been very helpful in providing us with information and advising on the data analysis. But the structure of the electricity supply system places NGC in a paradoxical situation. NGC is the system operator and integrator but also a private company with shareholder obligations. As system operator, it is the organization best placed to advise the government on the most energy efficient clock time regime, but as a private company it has no economic incentive to do so. Thus "National Grid has to be very careful about supporting a particular initiative and always aims to be seen as providing a "level playing field" to the electricity Supply Industry. (private communication to the authors)" A recent *Financial Times* article entitled "*Help us sell less power, National Grid tells regulators*"[18] cites the CEO of NGC, Steve Holliday advising the government that: "*Energy companies have clearly been motivated by selling units of energy. You've got to turn this completely on its head.*"

The National Grid Company supported Tim Yeo's Lighter Evenings Bill for the following reasons, as cited in a communication based on parliamentary questioning.

National Grid Spokesman: "The delay in the darkness peak demand causes a reduction with the ramp in to the peak being reduced. Energy consumption could also decease due to the shorter duration of domestic lighting etc in the evening only partly offset by additional lighting etc. in the darker mornings.

Q. Does National Grid support a change to daylight savings time [Tim Yeo's Private

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[17] House of Commons Hansard, 8 Dec 2004: 584W.

[18] The Financial Times, National News 08th May 2007.

Members Bill] in order to help tackle climate change?

National Grid Co. Spokesman: In terms of energy consumption there would be some reduction in energy demand and this would therefore be positive in terms of tackling climate change." [19]

The Scottish Dimension and Electoral considerations

The key issue on which recent private member's bills have foundered in attempting to effect a change in clock time regime is the Scottish issue. Scotland has 9.5% of the population of the UK. Former prime minister, James Callaghan, was a strong promoter of GMT+1 all year. His remarks during the debate on the 1968-71 experiment are particularly relevant to Scotland where hours of daylight in winter are much more limited than in the south: *"The plain truth is … we do not have sufficient hours of daylight in winter, and it is a question of how we best dispose of them to the best advantage. There are just not enough hours of daylight to go round, and however we play with them … we shall not satisfy everyone."* [20] In these conditions it would appear all the more important that policy decisions be made with reference to full and objective evidence on the impact of clock time rather than in response to vocal opinion based on partial evidence.

Scottish MPs have not been provided with comprehensive and clearly explained evidence. The reduction in road accidents from changing to GMT+1 all year would be no less in Scotland than the UK as a whole. This was known at the time of the 1968-71 debate as the 1970 Hansard record confirms.[21] *"We have the statistics of the causalities. In England and Wales there was a betterment of 3 per cent. In Scotland … there was a betterment of 8.6%."* At the time of the debate these statistics were questioned, but a series of research studies since 1995 on more current Scottish accident data have confirmed the unfavourable impact of GMT, resulting in around 40 unnecessary deaths and serious injuries on Scottish roads annually.

Opponents of the proposed policy change have not produced evidence demonstrating that Scotland would consume more energy under GMT+1. Our preliminary analysis suggested

[19] Communication from.National Grid Co. to the authors 11.10.07

[20] House of Commons Hansard, 02nd Dec 1970 c.1360-1361.

[21] House of Commons Hansard, 02nd Dec 1970 c.1340.

that the impact of a move to GMT+1 in winter would be neutral for Scotland. The gains would be less than further south during the period when, even under GMT+1, dark falls before the afternoon "hump" in energy consumption. But the price of electricity is the same over the whole of GB.[22] When the price of electricity rises elsewhere in GB as a result of higher demand peaks from early onset of dark under GMT, this higher price affects consumers in Scotland no less than those in England and Wales.[23]

Despite this evidence, the proposed change in clock time policy has been presented as harmful to the Scottish population. During the second reading of the "*Energy Saving (Daylight)*" Bill on the 26th of January 2007, there were 260 interventions, of which 109 from Scottish MPs who make up 32 members of the House of Commons. The Bill was consequently "talked out," a common tactic for defeating a private member's bill.

Concluding Observations

The government does not contest the figures relating to the potential road accident savings. During a debate in 2005 in the House of Lords, the government spokesman stated: "*The facts are that you would save 100 lives and 300 serious injuries each year. Those figures are based on what happened in 1968–71, so they have been known for an extremely long time. Parliament, knowing those figures, took the decision it did.*"[24]

The question arises as to why the government is not swayed by these figures. One explanation is that Scottish electoral considerations are overriding. The government's position is that the present clock time policy is a "satisfactory compromise" but this may take the form of concessions to vocal interest groups as against the unvoiced interests of the rest of the population. However, electoral opportunism on the part of successive governments may not be the primary explanation of policy inertia on this issue since 1971. The governments' position can also be explained with reference to research on common cognitive errors in decision making. We have seen the robust data on accidents dismissed through failure to correct earlier incomplete evidence. The psychologist, Daniel Kahneman, Nobel laureate in economics, has also shown from experimental evidence that people tend to be risk

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[22] http://www.statistics.gov.uk/downloads/theme_population/PopulationTrends128.pdf (accessed on 1st August 2007).

[23] BETTA introduced a single wholesale electricity market for the whole of GB on 1st April 2005: http://www.dti.gov.uk/energy/markets/electricity-markets/betta/page30130.html

[24] House of Lords Hansard, 07 Nov 2005 c.389.

adverse about change even when the change is likely to result in gains, more especially if these gains are viewed as small (Kahneman 2002).[25] As regards gains in terms of energy savings, it has been assumed by government experts that these are too small to be worth systematic inquiry even though available evidence shows the gains from change to be much greater than the costs.

The accident effect of GMT cannot be dismissed as small. Without counting the thousands seriously injured since 1971when GMT was reintroduced in winter, at least 100 people have died unnecessarily on the roads every year as a result of GMT. Thus at least 3600 lives could have been saved by a change in clock time policy (the number of people killed in NY on 9/11/2001).

Economists often have to deal with differences in death rates associated with alternative policies. But in this case there is no trade off to show that current accident figures represent a lesser evil. Taken together since 1971, avoidable fatalities and serious injuries amount to around 20,000. Quite independently of energy costs (to which they contribute) these tragedies justify making GMT a scientific measurement and moving clock time in the UK one or two hours forward.

Reckoned cumulatively since the reimposition of GMT in 1971, a 2.2% daily saving in electricity consumption from remaining on GMT+1 could have supplied the population of Greater London with electricity for 2 years at current consumption rates.[26] No less significant is the cost entailed by this wastage of electricity. A reduction in daily electricity consumption of around 2% attributable to a GMT clock time should be considered in relation to peak demand effects. The increase in generation costs attributable to GMT in winter are much higher than the increase caused in consumption of electricity because of recourse to reserve energy sources during peaks in demand. Increases in the price of electricity have knock-on effects for the whole economy.

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[25] The Nobel Prize was awarded to Kahneman for "having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty" (Kahneman 2002).

[26] Calculated by obtaining the average 2006 electricity consumption per person.

Climate Change Issues

The issue of clock time has not been investigated in the UK in connection with the campaign to reduce carbon emissions.[27] Although the exact value of electricity savings cannot be calculated in the absence of actual current data on GMT+1 in winter, that there would be savings is not in question. This can be inferred directly from electricity demand profiles and activity patterns.

According to the regression analysis presented above, which had a conservative bias, if GMT+1 had been implemented in winter of 2006, electricity savings would have been 2.78 million MWhs over the twenty one weeks of GMT.[28] Emissions of this order create in the region of 1.2 million tonnes CO_2.[29] The cumulative extra carbon emissions released due to the return to GMT during winter months over the whole period since GMT was re-imposed in winter, that is over the years 1971-2006, can be estimated in the order of 46.4 million tonnes CO_2. Since carbon emissions exert a cumulative effect, this CO_2 will have built up and remained in the atmosphere.

Climate Change and the Timing of Daylight Hours

We are increasingly enjoined to alter our way of life to reduce harmful effects of rising electricity consumption. However the government has maintained that an institutional innovation of this kind requires a change in public opinion, which in turn requires that the relevant evidence be brought home to the public. Using clock change to reduce demand for artificial lighting may appear to be a relatively simple measure. But to optimize the use of natural daylight would require a change of mindset. Wasted daylight and the emissions consequently pumped into the atmosphere would have to be viewed with the distaste that is now felt about dumping sewage into rivers.

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[27] The draft Climate Change Bill of 13th March 2007 commits the UK to a 60% cut in the UK's carbon emissions by 2050, with an intermediate target of 26-32% by 2020.[27] These emissions cuts will be legally binding on parliament to achieve. An independent Committee on Climate Change will be set up to advise on policies required to meet this target.

[28] The sum of 18942 MWh per day over 21 weeks of GMT, the finding of the regression analysis p.15.

[29] We can use these figures to estimate cumulative effects of the return to GMT in winter since 1971. Based on electricity demand data supplied by the NGC. DTI conversion figures: 0.43tCO2 / MWh. Average annual consumption in 1971 was 36.8% less than it was in 2006 though more emission intensive pro rata.

At the root of the issue is the mismatch between traditional clock time and activity patterns today. People no longer rise at dawn and centre their activities around noon time. Standardising clock change nationally and Europe-wide has many benefits. But uniformity in official clock time also results in disparities between natural light and local needs or preferences. To reconcile standard time with diverse needs, more could be done to align working hours and activities according to the local availability of natural daylight, rather than with official clock time.[30] Early morning workers could arrange to work different seasonal shift times, starting later in winter and earlier in summer. This is the practice in Scandinavian countries (Hillman 1993). There is scope for much more use of flexible working time to provide choice in adapting to daylight hours.

We could reconsider the words of Benjamin Franklin in the *Journal de Paris* in 1784, where he expressed his dismay that people's waking hours and the period of sunlight were so mismatched (Prerau, 2005). He asked why people should live by the "*smoky, unwholesome, and enormously expensive light of candles* [*when*] *they might have had as much pure light of the sun for nothing?*" The word "candles" could be replaced with "fossil fuel" in public debate on this issue today.

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[30] This is done in China, with its unitary Beijing clock time.

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APPENDIX A Data Sources and Terminology

Electricity Data

National demand data at 30 minute intervals for the period 2001-2006 was provided by the National Grid Company (NGC) for this study. Data for recent years is available on the NGC website. [31] The power of electricity flowing through the transmission network of the National Grid Company is balanced in response to demand for power, and hence is termed “demand’ by the NGC; since this is a measure of power, units are in MW. Energy usage over a specified time period is called “consumption” and is measured in MW hours.

The standard unit of analysis for electricity demand is the Kilowatt-hour (or at high levels, the Megawatt-hour (MWh) or Gigawatt hour (thousands of MWhs)). On a domestic bill, one unit of electricity relates to one kilowatt-hour. This is equivalent to one kilowatt of power being drawn continuously for an hour by the consumer.

Astronomical data

Sunrise, sunset and hours of daylight data presented in this report was obtained from the website: www.timeanddate.com run by the Norwegian company, Time and Date AS. The data from this website were crosschecked with the service provided by the United States Naval Observatory[32] and were found to be in agreement.

Temperature data

Historical temperature data for the United Kingdom was taken from the Hadley Centre website. Where a representative temperature for the UK was needed, the Hadley Centre’s ‘central England temperature index’ was taken.[33]

Nomenclature

GMT	Greenwich Mean Time
BST	British Summer Time (GMT+1)
SDST	Single/Double Summer Time (GMT+1hr in winter, GMT+2hrs in summer)

[31] www.nationalgrid.com/uk/electricity/data/demand+data (accessed on 2nd August 2007).

[32] http://aa.usno.navy.mil/ (accessed on 2nd August 2007).

[33] http://badc.nerc.ac.uk/data/cet/ (accessed on 2nd August 2007).

CET Central European Time (GMT+1 in winter, GMT+2 in summer)

Correction for holidays in Clock Change week comparisons (in Appendix D)

Average daily demand fluctuates to some extent during the week but is relatively constant when compared with weekend demand, which tends to be much lower. During public holidays weekday demand can be expected to drop to weekend levels. A substitution of the nearest working day was made for holiday consumption for clock change week comparisons, but not for the regression analysis where week ends and holidays were entered as a binary variable. The holidays which might influence weekly trend analysis are the Easter Friday and Monday holidays in 2002 and 2005. In order to remove the holiday effect (which occurred both before and after the clock change, as the date of Easter varies) Friday was replaced with the data from the previous day, which was a normal working day. Monday was replaced with the data for the following day. In effect, these weeks were treated as having "two Thursdays" instead of a Thursday and Friday and "two Mondays" instead of Monday and Tuesday. In order to remove any possible bias, in the weeks previous to and following the holidays for the years involved a substitution was effected. This substitution is applied data used for calculations of both GMT and GMT+1 effects and allows us to compare equal periods of time across years without the distortion of different holiday dates.

In the regression analyses, week-ends and holidays were treated as a binary variable.

Appendix C: Portuguese Experiment with Central European Time, 1992-96

A House of Commons briefing for MPs emphasized need to learn from the Portugese experiment with clock time. From 1992 to 1996 Portugal changed its time zone from a

GMT/GMT+1 time regime (as is currently implemented in the UK) to a GMT+1/GMT+2 time regime to harmonize with European partners.

However the Portuguese experiment has limited relevance to the issue of assessing the effects in GB of GMT in winter because of geographical difference between Portugal and the UK. The capital of Portugal, Lisbon lies 800km west of the Greenwich meridian and so already experiences lighter evenings than the UK, as can be seen from the graph of sunrise and sunset in London and Lisbon below.

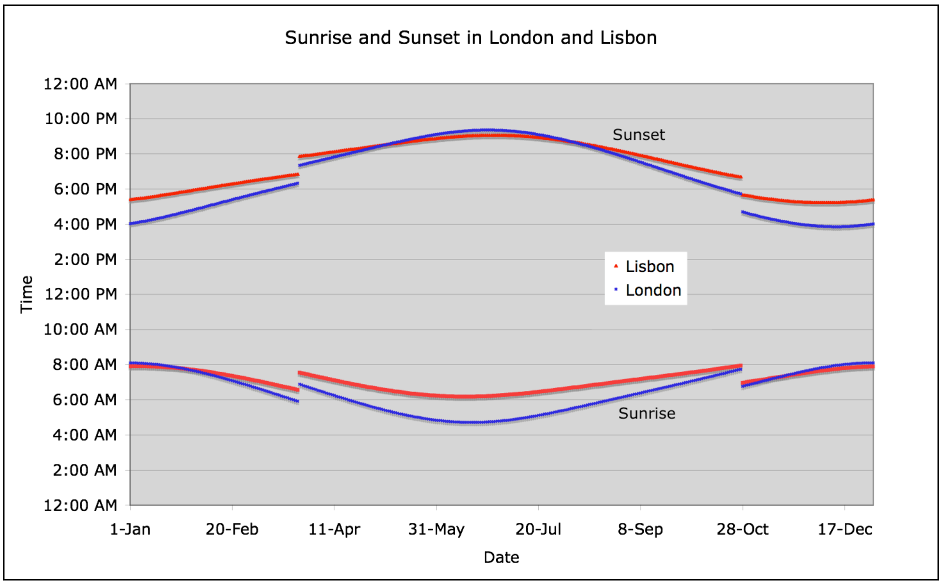

Figure C.1 Comparison of sunrise and sunset in London and Lisbon

On average, the sun rises and sets 36 minutes later in the day in Lisbon compared to London, even though the time zones of the two cities are identical. It can be seen from figure C.1 that this effect is most noticeable in the winter months. During the winter period, although both regions are on GMT, the sunsets an average of 1 hour and 07 minutes later in Portugal than in the UK. Thus, Portugal is effectively 1 hour ahead in winter compared to the UK already, despite being on the same time regime.

Objections in Portugal centred on GMT+2 in summer. The summer time regime apparently disrupted sleep patterns, particularly among children, as the sun did not set until 10.30 pm during the peak of summer, a situation to which the population adapted further north. Car insurance data suggested that lighter evenings might have brought more cars onto the roads, but it is not clear what the net effect was on accidents. [34]

[34] http://www.oal.ul.pt/oobservatorio/vol8/n2/vol8n2_2.html (accessed on 4th August 2007)

APPENDIX D

A trend comparison of electricity consumption over clock change weeks

To gain a better understanding of the factors shaping the findings of the regression analysis we developed an alternative approach that involved a different methodology. This method is based on the clock change weeks providing what amounts to a twice-yearly demonstration of how much the pattern of electricity demand changes in response to an abrupt shift in clock time regime. This method cannot control statistically for fluctuations against the seasonal trend. Although from one week to the next seasonal effects are not high on average, the nature of seasonal fluctuations vary considerably from year to year, so that findings will depend on the years selected for analysis.

The methodology for comparing clock change weeks

The logic followed was to use the two weeks prior to the clock change to forecast the electricity consumption during the week immediately after the spring and autumn clock change *had no clock change taken place*. The difference in energy consumed can then be calculated:

> The subscript AC is used to refer to weeks after the clock **c**hange.
>
> The subscript BC is used to weeks before the clock change.
>
> The subscripts are numbered to indicate the number of weeks before or after the clock change. For example $week_{AC2}$ refers to the amount of electricity consumption during the 2nd week before the clock change.

A value was then obtained for predicted consumption over the subsequent week when a clock change did occur, assuming a similar change to that found between the weeks when no clock change occurred. This was then compared with the change that actually occurred. We used the following equation:

$$\Delta\text{energy consumption} = week_{AC1predicted} - week_{AC1actual} \qquad \text{...........(1)}$$

$$week_{AC1predicted} = week_{BC1} + (week_{BC1} - week_{BC2})$$

Substituting this back into the equation (I) we can isolate the effect of the clock change:

$$\Delta\text{electricity consumption} = 2*week_{BC1} - week_{BC2} - week_{AC1actual}$$

Given the linear change in daylight through the year (Fig. 5) and the proximity of weeks analysed, this method accounts implicitly for daylight effects and, on average, for seasonal temperature change. Averaging of the annual results was carried out to smooth the yearly fluctuations caused by temperature variation. The more years selected for averaging the better the confidence will be in the results.

The clock change weeks are analyzed and averaged for the last 6 years, to provide enough data points to average out annual fluctuations. The most recent demand profiles display an evening peak in demand. In the demand profiles from 1962 and 1972 (figure D1) this peak is absent.

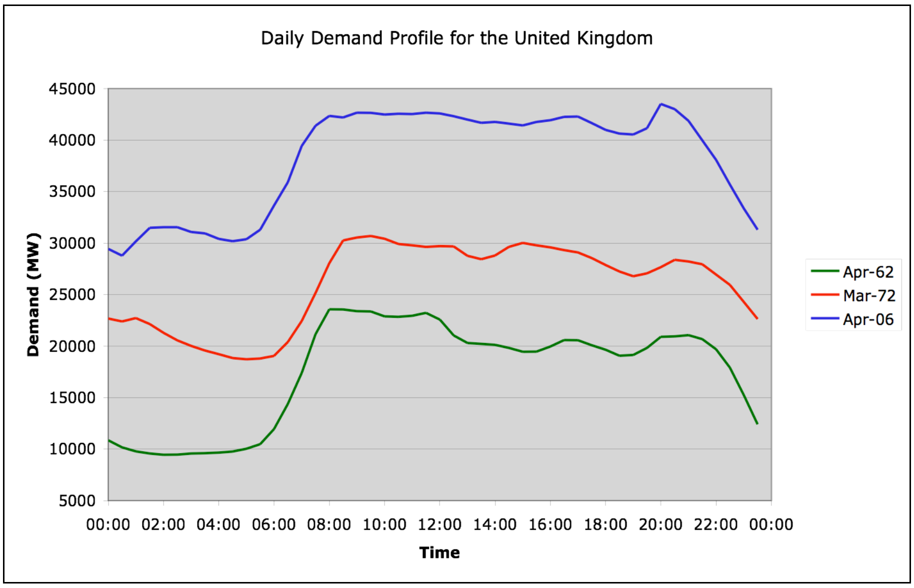

Figure D1: Demand Profiles in the UK over the past 40 years.

As the UK economy has become less industrialized over the past 30 years, the pattern of domestic demand has more influence over the overall demand profile. Thus the evening peak of demand caused by people returning from work has more of an impact. No significant change in the demand profile has occurred since 2001. Analyzing years too far in the past may not be relevant today. Figure 6 shows how the daily demand profile has been changing over time in the UK.

Tables D1 and D2 below summarize results of the clock change week comparison from 2001-2006. Column 3 shows difference between the average temperatures during the week before and after the clock change.[35] Years in which temperature fluctuated from week to week against the seasonal trend are shown in grey; these will swamp the effect of the clock change, but are used in the calculations, making it likely that the clock change effect will appear lower than the figure shown by the regression analysis.[36]

Year	Change in Energy consumed (MWh)	Temperature change (°C)
2001	-500587	2.2
2002	-25611	2.9
2003	250234	-0.5
2004	-503975	3.8
2005	524509	-2.0
2006	-371346	5.5
Average	-104463	2.0

Table D1: Change in Energy Consumed, and temperature change, week after spring clock change from GMT to GMT+1, GB 2001-2006.

Year	Change in Energy consumed (MWh)	Temperature change (°C)
2001	129866	-1.7
2002	-131017	0.6
2003	-445532	0.9
2004	279917	-1.2
2005	141668	-1.6
2006	169098	-3.5
Average	24000	-1.1

Table D2: Change in Energy Consumed, and temperature change, week after autumn clock change from GMT+1 to GMT, GB, 2001-2006.

[35] The temperatures used are the UK Hadley Centre's "Central England Temperature Index". The average change over 50 years for these weeks is +0.60°C in March and -0.59 °C in October.

[36] Although overall the NG has found a reduction in consumption of 350 MW with every degree Celsius rise in temperature, the amount of increase in consumption varies with absolute temperature and with other factors, so this rule of thumb is not accurate enough to guide estimation.

Table D2 provides another conservative estimate of the impact of GMT on electricity consumption, showing a fall in energy consumption with the clock change from GMT onto GMT+1 in spring which amounted to 104,463 MWh over the clock change week. In contrast, there was an increase in electricity consumption associated with the move from GMT+1 back to GMT, in autumn by 24,000 MWh (Table D2). Years during which energy consumption did not fall with GMT+1 are shown in grey; they correspond with dates when temperature fluctuated against the seasonal trend, decreasing as March advanced and increasing as October ended.

	Additional electricity consumed under GMT over 1 week (MWh)	**Additional Electricity Consumed under GMT per day (from col. 2)**	**Additional electricity consumed on GMT instead of GMT+1: % increase Per week**	**Per day**	**Associated Emissions (tonnes CO_2)[37]**
Autumn Clock Change week	24,000	3429	0.39	0.4	10,320
Spring Clock Change week	104,463	14924	1.71	1.6	44,919
Total extra consumption Both weeks	128,463	Not estimated	Not estimated		Not estimated

Table D2: Additional Electricity Consumed in Great Britain 2001-2006 over clock change weeks attributable to regime of GMT as clock time.
(Data for all years used from Tables 4 and 5).

The regression analysis presented in the text of this report allows more systematically for seasonal fluctuations that affect averages than does the method shown in Table D2. The regression analysis found daily consumption increase on GMT (as compared with what it would have been on GMT+1) to be 18,492 per day (129,444 MWhs per week) during the months of GMT. This was a 2.2% increase in average daily electricity consumption on GMT

[37] CO2 conversion is 0.6 tCO_2/MWh: http://www.defra.gov.uk/environment/climatechange/trading/uk/reports.htm accessed on 20th August 2007.

above what consumption would have been on GMT+1 during the GMT weeks. The regression finding is closer to the spring than the autumn estimate found using the clock change week comparison method.

The effect of GMT on electricity consumption is found to be much greater in spring than in autumn by this method, which is consistent with seasonal trends: temperature is around 2 degrees colder at the end of March than at the end of October and there are two more hours of daylight in March. This makes it possible to time sunset after the return to work peak by moving the clock forward in March. As analysis of peak hour demand by season (not shown here) revealed, when hours of daylight are shorter, the gain/loss in electricity consumption is more constrained and shows less effect from shifting the timing of sunset to reduce peaks.