THE IMPACT OF THE ANOMALOUS WEATHER OF 1995 ON THE U.K. ECONOMY

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Abstract. This study assesses selected impacts on tertiary activities of the anomalously hot summer of 1995 and warm period from November 1994 through October 1995 in the U.K. Over this period, the mean Central England temperature was 1.6 °C above the 1961–1990 normal, representing the highest mean 12-month temperature since the start of the Central England temperature record in 1659. The study is distinguished by its breadth of coverage, for it includes tertiary sectors and activities. Although impacts in tertiary activities are often not included in assessments of the potential impacts of climatic change, many of these activities are very important to the U.K. economy, and therefore even a small perturbation in output due to a weather extreme can have significant implications for the economy as a whole. The activities and sectors studied include energy consumption, retailing and manufacturing, construction and buildings, tourism, health, human behaviour, and fires. Both negative and positive impacts were incurred within most sectors. Net positive impacts (to the general public) were found convincingly for energy consumption and health, and clear negative impacts for buildings insurance and fires. Sectors which show clear differences in their response to winter and summer warm anomalies are energy consumption, tourism and health (greater sensitivity to winter anomalies) and buildings insurance and fires (greater sensitivity to summer anomalies). Changes in sensitivity to climate extremes may have occurred over time, and a comparison of impacts of the 1995 anomalous weather with the unusually warm dry period of 1975–1976 is approached for several series.

1. Introduction

The 'high' summer of 1995 (July and August) was the hottest recorded in the long Central England temperature series and was embedded within a twelve-month period that was also the warmest on record. This period of anomalous weather provided an opportunity to study impacts of warmer, drier weather over a range of economic and social sectors. The weather extreme provides an analogue of possible

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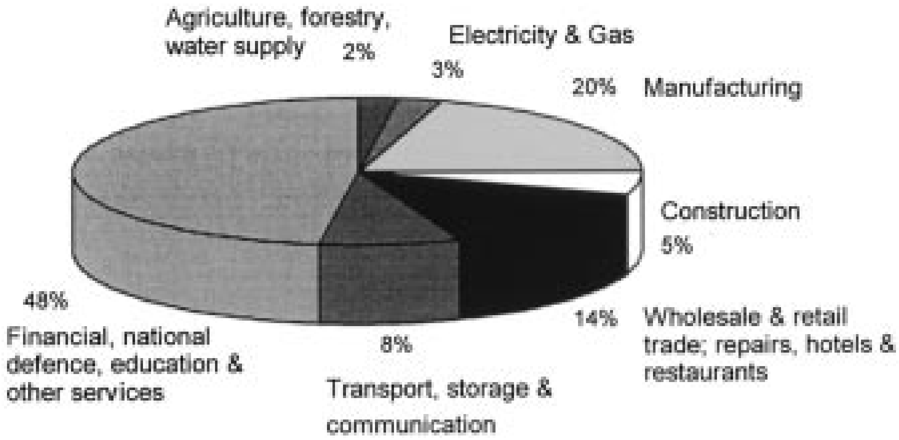

Figure 1. Percentage contribution of U.K. GDP in 1995.

impacts to be expected from climatic change, regardless of whether the extreme was induced by human interference in the climate system.

With the aim of empirically improving our understanding of Britain's sensitivity to climate change, the U.K. Department of the Environment sponsored a study to assess economic impacts of the unusually warm year of 1995 (Palutikof et al., 1997). The study, upon which this article is based, analyzed impacts of the 1995 weather within the context of climate conditions during the past two decades, including the unusually warm, dry period of 1975–1976 in the U.K. Because the analysis was conducted where possible with monthly data, an exploration of differences between winter and summer sensitivity could also be pursued. The original study included analysis of impacts of the 1995 warm weather on the water-limited impact categories of agriculture, forestry, the natural environment and water supply, in addition to the secondary and tertiary activities assessed in this paper. In the U.K., the primary sectors of agriculture and forestry make up only about 2% of U.K. output, whereas the secondary and tertiary sectors of energy, construction, manufacturing, retailing and tourism contribute about 40% to U.K. GDP. Unlike the water-limited sectors, climate-activity relationships for the tertiary and service sectors are not yet well understood and it is the exploration of the magnitude and timing of the response of these activities to warmer weather that is taken up as the subject of this paper.

This study adds to a growing literature on economic impacts of discreet periods of anomalous climate in the late 20th century. A range of studies analyzing costs and benefits of extreme events in Australia include investigations of tropical storms and bushfires (Ryan, 1993), flood damage (Joy, 1993), and weather changes related to the El Niño Southern Oscillation (Colls, 1993). Several studies of impacts of unusually warm and dry weather have also been completed. A German study examined economic impacts of the hot summer of 1992 on the northeast region of the country (PIK, 1994). In the U.K., the effects of the warm years of 1989 and

1990 have been analyzed principally for their impacts on the natural environment and primary economic sectors (Cannell and Pitcairn, 1993).

This study of the warm year of 1995 in the U.K. is relatively comprehensive and includes analysis of climate-activity relationships that have not been previously explored in this country. A monetary assessment was undertaken where possible with economic impacts specified as changes in consumer expenditures, public expenditures and/or producer costs. The results are preliminary only. While this study addresses possible economic impacts of a discrete one year weather anomaly, and not of a climate change, the extreme weather experienced in the U.K. in 1995 may be expected to recur with greater frequency during the next century in response to the enhanced greenhouse effect. This analogue approach has value as a tool to demonstrate the possible sensitivities of these sectors to climatic change. The relevance of the results to climatic change is less for sectors and activities where options for adaptation are considerable and not costly to implement, e.g., technological and managerial responses in agriculture, or where adaptive responses are expensive but believed to be necessary, e.g., water supply development. The analogue tends to be stronger for tertiary activities than for primary sectors because for these activities little or no institutional adaptation is required, e.g., household consumption of heating fuel, or for activities where adaptations are unlikely to be implemented because of cost or other difficulty, e.g., outdoor fire occurrence. For these activities especially, we believe that empirical analysis of actual impacts of weather extremes can lay the basis for a better understanding of the potential impacts of climatic change.

2. Climatology

We use two composite climate time series, compiled from a number of reliable station records, to judge the exceptional character of the period of interest. The first is Central England temperature (CET), which provides monthly mean temperatures extending back to 1659 (Manley, 1974; Parker et al., 1992 and updated). The second is England and Wales precipitation (EWP), a monthly time series of precipitation totals which commences in 1766 and, over the period of interest here, is derived from data from 35 station records across the region (Wigley et al., 1984; Jones and Conway, 1997 and updated).

The twelve-month period from November 1994 to October 1995 in the U.K. was the warmest on record, with a CET anomaly from the average recorded between 1961 and 1990 of 1.6 °C (see Table I). The 1995 high summer period (July and August) was the warmest and driest on record. The warmth began in the last week of June, and the mean July and August Central England temperature was 3 °C higher than the 1961–1990 baseline. Total England and Wales precipitation for July and August was only 47 mm compared to a 1961–1990 average of 139 mm.

TABLE I

Central England Temperature during the period November 1994 to October 1995 as an anomaly from the 1961–1990 average, and as a rank in the full 337-year CET series (1 = warmest; 337 = coldest)

	Anomaly (°C)	Rank		Anomaly (°C)	Rank
November	3.6	1	May	0.4	107
December	1.8	28	June	0.2	163
January	1.0	70	July	2.5	5
February	2.7	17	August	3.4	1
March	–0.1	140	September	0.1	118
April	1.1	107	October	2.3	2
July–August	3.0	1	November–October	1.6	1

TABLE II

England and Wales precipitation amounts for relevant periods and 30-yr normal (mm)

1975/1976		1994/1995		1961–1990	
Autumn 1975	218	Autumn 1994	298	Autumn	246
Winter 1975/1976	146	Winter 1994/1995	415	Winter	236
Spring 1976	129	Spring 1995	147	Spring	195
Summer 1976	74	Summer 1995	67	Summer	202

For the U.K., the closest analogue for the 1995 extreme is the period 1975–1976, described by Doornkamp et al. (1980), and in particular the summer of 1976. Although the July and August 1976 mean CET temperature was exceeded in both 1983 and 1995, the CET mean temperature for the three summer months of 1976 is still the highest on record, at 17.8 °C. This was the culmination of a period of extreme conditions beginning in the summer of 1975, which was the third warmest summer after 1976 and 1995.

Relatively wet conditions preceding the 1995 extreme summer were important in determining the nature of the impact. The winter of 1994/1995 was very wet, with an EWP total for December to February of 415 mm, 75% above the 1961–1990 mean value. Although spring was dry (EWP only 75% of the 1961–1990 mean), water resources were less severely affected in summer 1995 than in 1976, when the very dry conditions over the preceding period (see Table II) meant that water supplies in some areas had to be rationed by stand pipes and rota cuts.

Although water supply companies which rely on surface supplies did experience some problems in the latter half of 1995, companies relying on groundwater were much less affected.

3. Methodology

So far as possible, we attempted to impose a common framework on the analyses for each sector. The primary sources of information were published government statistics, and in particular the *Monthly Digest of Statistics*, produced by the Office for National Statistics (Central Statistical Office, 1972–1996). Official publications were supplemented with sources such as company Annual Reports and Web pages, and enquiries by telephone and letter. Analysis was undertaken at the national, rather than regional level. This was partly to avoid the practical problem of analyzing a large number of regional datasets that involve longer time lags before publication. However, analysis of the relationships between national, rather than regional, activity data and climate data appeared to be reasonable in part because the spatial area of U.K. economic activity is relatively small and deviations from the single Central England temperature series across the country are low. The correlation between station temperature anomalies in the British Isles and CET only falls to below 0.8 for annual temperatures in the Northern Isles of Scotland (Jones and Hulme, 1997). Precipitation levels vary to a greater extent than temperature over the whole of the U.K.

The common analysis method was as follows. Activity time series were selected on the basis that they were expected to demonstrate the sensitivity (or otherwise) of a particular sector. For example, for retailing the three selected series were clothing and footwear, fruit and vegetable, and total volume retail sales. Long time series of these indices were then extracted. Where possible, the series extended back to the early 1970s, in order that the impacts sustained in 1995 could be compared with those for the 1975–1976 period. The intention was to investigate whether sensitivities to climate extremes had changed over the two decades. The time series were then inspected and any long-term trend removed, under the assumption that such trends are related to factors other than climate. A variety of techniques were used to define the long-term trend: in some cases a linear trendline was sufficient, but polynomials and running means were also employed where inspection suggested these were appropriate. The assumption is that the residuals from the long-term trend encapsulate short-term fluctuations in activity due to anomalous weather conditions. Hence regression analysis was performed using these residuals as the dependent variable, and a range of climate variables as independent variables. The climate variables employed for the analysis of tertiary activities were:

(i) Central England temperature (Manley, 1974; Parker et al., 1992),

(ii) England and Wales precipitation (Wigley et al., 1984; Jones and Conway, 1997), and

(iii) England and Wales sunshine (compiled from between 10 and 20 station records, and provided by the U.K. Hadley Centre (M. Harrison, personal communication)).

All were available as monthly time series. In addition, monthly degree-day totals were calculated from the daily Central England temperature (CET) series, and were used in the energy sector analysis. These were found to correlate less well with energy consumption than CET alone, and so are not considered further here.

We use these climate variables in order to capture a clear representation of the climatology of 1995. Individual station records will be contaminated by conditions in the local environment. One of the reasons for compiling records such as CET is to separate the signal of the large-scale variability from the noise of local weather. Such records are therefore very useful for our purpose, which is to examine the relationship between weather variations and national indicators of the socio-economic impacts of the weather of 1995. By using regression analysis as the statistical tool to link the climate variables to the impact, we are deliberately taking a 'black-box' approach. Such an approach permits exploration of climate-impacts relationships even when the exact chain of causality is not well understood, for example in the cases of manufacturing industry and retailing. Where the relationships are well understood, for example in the case of energy, the use of regression analysis allows rigorous quantification of the impact.

For some sectors, human response to weather was instantaneous and the relationships clear (e.g., the energy sector, where current-month temperature is the most important predictor). In others, the relationships were not clear, and lag effects were expected to be significant. In sectors such as retailing and manufacturing, stepwise regression techniques were therefore used. Rainfall, temperature and sunshine variables were offered as candidate predictors, for the same month and for a number of preceding months. In these cases, the predictor variables were standardized.

Where the climate variables are significant predictors of the residuals, the regression equation can be used to predict the expected impact of the weather variables over the full time series. For the two critical years, 1976 and 1995, the predicted impact was then compared with the actual impact (as given by the actual residual from the long-term trend). The predicted impact was used, data availability permitting, to place a monetary value on the impacts of the extreme conditions of 1976 and 1995.

This approach worked very successfully in some sectors. For energy consumption and outdoor fires, for example, strong and reasonable relationships were found, as expected. For other sectors, such as manufacturing, retailing and tourism, the relationships were more complex and less easy to explain. Although activity series were selected for their importance within the economy and for their suspected sensitivity to weather, the series analyzed cannot be regarded as comprehensive for any individual sector. The tertiary sectors and activities selected for this paper are only a part of economic sectors that make up less than half of U.K. output. Other service activities such as financial services, real estate, education, etc., contribute about 50% of domestic output (Central Statistical Office, 1996), but we lacked a working hypothesis as to the sensitivity of these activities to climate, which were therefore not studied.

Many impacts involve transfers within the economy and not, therefore, changes in overall economic efficiency. What is a cost to one sector may well emerge as a benefit in another. For example, reduced spending on indoor leisure activities in hot weather may appear as increased spending on accommodation during day trips and weekend breaks. Furthermore, an immediate impact due to the fine weather of the summer of 1995, such as increased spending on short holidays, may well have later negative impacts on spending in general where consumers' income is fixed. A further and related problem is that of 'double counting'. For example, expenditure on tourism, considered here as a separate entity, is a composite involving amongst other things spending on retailing. Therefore, estimated impacts on individual sectors and activities cannot be translated directly into an impact on tertiary sectors as a whole.

4. Sectoral Discussion

While a consistent methodological approach was sought for the range of tertiary impact categories covered, a difference in data quality and length of available, homogenous, economic time series was encountered. To illustrate the general approach and problems found in identifying weather relationships and putting a value on them, two activity categories have been selected to discuss in greater detail in this paper: energy consumption and production in the food, drink and tobacco industries. In the case of energy consumption, the data series are accurate, lengthy and homogenous, and the implications of the statistical relationships for changes in consumer expenditures are clear. Analysis of the manufacturing series for food, drink and tobacco is described here to illustrate some of the difficulties more commonly encountered.

4.1. ENERGY

4.1.1. *Data Selection*

While it is stating the obvious that in exceptionally hot summers and mild winters people will use less heating in the home than usual, here we attempt to quantify the extent of the reduction, to assign it a monetary value, and to determine how it varies between fuel type. The possible role of increased use of air conditioning is also investigated. Gas and electricity were chosen as indicator fuels in the energy sector because they are most closely associated with space heating. About 60% of residential fuel use is natural gas, with electricity comprising half of the rest at

TABLE III

Correlation coefficient (r) between the mean monthly CET/monthly number of CET and the adjusted monthly energy variables (1972–1995)

Month	r (gas)	r (electricity)	r (motor spirit)
Jan	**–0.66**	**–0.52**	*
Feb	**–0.85**	*	**+0.57**
Mar	**–0.68**	*	+0.47
Apr	**–0.69**	–0.42	*
May	**–0.64**	*	*
Jun	**–0.58**	*	*
Jul	–0.41	*	–0.43
Aug	–0.44	*	*
Sep	**–0.53**	–0.48	*
Oct	**–0.72**	–0.45	*
Nov	**–0.78**	–0.47	*
Dec	**–0.61**	*	*

* = Not significant at $p < 0.05$; bold face, significant at $p < 0.01$, otherwise significant at $p < 0.05$.

20%. Air conditioning, which makes up only a small fraction of U.K. energy consumption, is almost exclusively electricity-based. Petroleum use (including motor spirit) was also examined because it accounts for a high proportion of total U.K. energy consumption at 43% (Department of Trade and Industry, 1996) and it is reasonable to assume that people may use motor vehicles more frequently when the weather is warmer in order to pursue leisure activities.

Data were available for total natural gas consumption, total deliveries of motor spirit, and total electricity consumption for each month from the Monthly Digest of Statistics (Central Statistical Office, 1972–1996). Gas and electricity consumption were also available by sector from the same source but only at the quarterly scale.

4.1.2. *Methodology*

The total gas, electricity and motor spirit data were detrended by making linear fits to the data for each month separately between 1972 and 1995. As the gas and electricity data showed a continuous upward trend for this period, a single linear fit could be used. Motor spirit consumption declines after 1990, because of greater diesel use, and therefore a separate fit was made between 1972 and 1990 and between 1991 and 1995 for this series. The adjusted data for each month were then correlated with and regressed on the monthly mean CET for the same month. Gas and electricity consumption data by sector type were analyzed using the same procedure but using quarterly data for fuel consumption and CET.

TABLE IV

Correlation coefficient (r) between mean quarterly CET and the adjusted quarterly sales by consumer types of gas and electricity (1972–1995)

Quarter	r (gas)				r (electricity)	
	Power stations	Iron/steel industry	Other industry	Domestic	Other[a]	Domestic
1	$*$	$*$	–0.41	**–0.85**	**–0.72**	$*$
2	$*$	$*$	$*$	**–0.70**	**–0.55**	$*$
3	$*$	$*$	$*$	**–0.74**	–0.50	**–0.52**
4	$*$	$*$	$*$	**–0.71**	**–0.60**	–0.47

$*$ = Not significant at $p < 0.05$; bold face, significant at $p < 0.01$, otherwise significant at $p < 0.05$.
[a] Public administration, commerce and agriculture.

4.1.3. *Results*

When monthly temperature was correlated with monthly gas, electricity and motor spirit consumption, by far the strongest correlations were found for gas (see Table III). Significant correlations were found for electricity for nearly half of the months and the strongest relationship was observed for the month of January. There is little evidence for any temperature dependence for motor spirit consumption for most months of the year although higher consumption was seen to correspond with warmer temperatures occurring in late winter months. The results for gas consumption were unequivocal. Significant correlations (at 95%) were found for all months and for all but two months the confidence in the statistical significance of the correlations was at least 99%. The high summer months of July and August had the weakest correlations.

As expected, because gas is the preferred fuel for domestic heating, the sectoral analysis revealed that the correlations for domestic gas customers are substantially higher than for the other sectors (Table IV). The correlations between quarterly adjusted sales to all other gas customers (representing public administration, commerce and agriculture) and the mean quarterly CET are significant at 95% confidence in only one of the four quarters. Significant relationships were not found for power stations or the iron/steel industries. For both domestic and ‘other’ customers, highest correlations are found in the first quarter (January–March). All of these customers would be expected to have a large space heating requirement. The correlation between quarterly adjusted sales of electricity to domestic customers and the mean quarterly CET is much lower, though highest (and significant) in the summer quarter.

When scattergrams are plotted between the 1972–1995 residuals of total gas consumption and CET for each month, we find that consumption in the warm period between November 1994 and October 1995 is substantially above the best-fit line for seven of these twelve months, indicating higher consumption than would be expected given the weather conditions. In contrast, the hot summer of 1976 produced values much closer to the regression line.

The picture changes when we examine gas consumption and CET scattergrams at the sectoral level. When we analyzed third quarter figures (July, August and September) for domestic, rather than total, gas consumption, the hot summer of 1995 shows the lowest quarterly consumption between 1972 and 1995 (and is below the regression line) (see Figure 2). Domestic gas consumption in the 1976 summer quarter lies a little above the best-fit line. These differences between 1976 and 1995 could be indicative of increasing sensitivity of consumption to warmer weather. However, the influence of structural changes in 1995 domestic gas consumption due to a change in appliance usage or lifestyle cannot be ruled out, because the 2nd and 4th quarters of 1995 also show the lowest quarterly consumption between 1972 and 1995 (and are below the regression line), although the temperature during these periods was not unusually warm (see Table I).

Although in the summer of 1995, domestic gas consumption was at its lowest, domestic electricity sales were above the best-fit trend line. (Incidentally, total electricity consumption was also particularly high in the third quarter of 1995). Tentatively, this may suggest an increased use of air conditioning and refrigeration equipment in summer in recent years.

4.1.4. *Discussion*

The economic impacts of the 1995 weather anomaly can be quantified based on domestic gas, 'other' gas and domestic electricity sales. We can calculate the impacts of the actual effect and the predicted effect. The actual effect is given by the difference between the linear trend with time fitted to the data, and the observed figure, multiplied by the unit price for 1995. The actual effect will contain the effects of factors other than climate. The predicted effect is given by the regression equations, which predict the anomaly fuel consumption from CET, again multiplied by the unit price. The assumption is made that the relationships between CET and consumption have remained stable over time. Predictions are made only for those quarters and energy consumption sectors where the statistical relationships are significant at the 99% level (see Table V).

The predicted effect may be greater than the actual effect, since of course the direction of other impacts may be opposed to the climate impact. In fact, for most quarters the actual is greater than the predicted effect. The actual change in gas consumption yielded estimated savings of £688 million, of which £441 million (predicted from the regression equations) can be assigned to temperature variations. The effect on domestic electricity consumption in 1995 can only be estimated for the third quarter, and the results in Table V illustrate some of the difficulties encountered in this approach. Whereas the predicted saving from the regression equation should have been around £60 million, there was an actual added cost of £34 million. This suggests that other factors were at work. Indeed

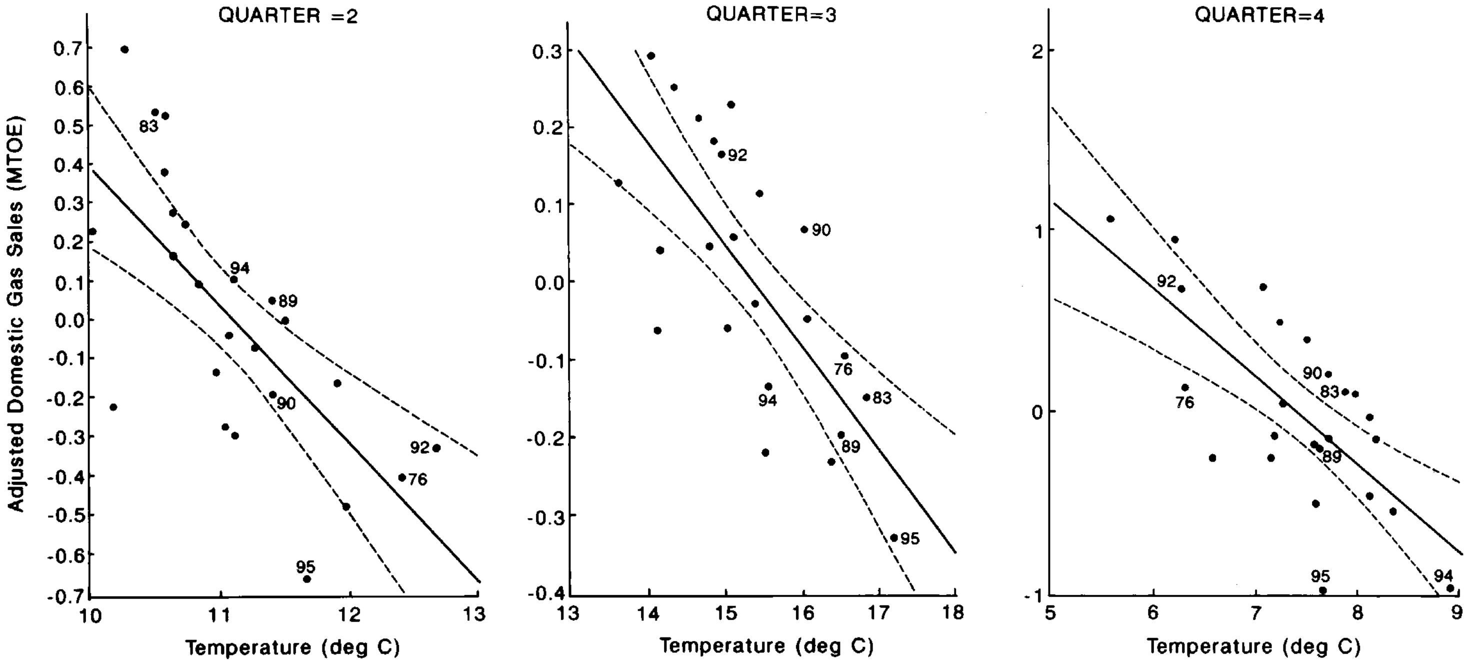

Figure 2. Adjusted domestic gas sales against mean CET for second, third and fourth quarters for 1972–1995. Dotted lines show 95% confidence limits on the regression lines. The years 1976 and 1995 are indicated.

TABLE V

Economic effect of anomalously warm weather on energy consumption (1995 prices)

Quarter	Actual effect (£M)	Predicted effect (£M)[a]
Domestic gas sales		
2/76	–90.7	–103.1
3/76	–22.3	–36.0
4/94	–219.6	–163.5
1/95	–139.8	–112.7
2/95	–149.7	–45.4
3/95	–74.4	–54.0
'Other' gas sales		
2/76	–6.7	–18.4
4/94	–94.9	–32.3
1/95	–20.1	–24.6
2/95	+10.1	–8.1
94/95 Total	–688	–441
Domestic electricity sales		
3/76	–89.3	–40.2
3/95	+33.9	–60.2

[a] Model relationships only included when significant at $p < 0.01$.

the correlation analysis had indicated that climate variables only explain about 50% of the variation in the residuals. One hypothesis, alluded to above, is that the temperature/electricity use relationships have not remained stable with time because increasing use of air conditioning and refrigeration equipment in the U.K. is leading to greater electricity use in hot weather.

If there were an increase in mean temperature in the U.K., the requirement for heating would drop for domestic and 'other' gas heating, with the financial impact being greatest during the winter months. The economic benefit of warmer winters for consumers would increase in the future if the price of gas increases, which it may with depletion of resources and rising use of gas by the industrial sector for electricity generation. A proportion of these savings would be lost if investments in air conditioning and refrigeration in the U.K. increase significantly in the future.

4.2. MANUFACTURING

4.2.1. *Data Selection*

Two time series of productivity in manufacturing were studied: food, drink and tobacco (FDT), and clothing and footwear. Here the analysis and results for FDT are described. We hypothesized that, in warmer weather, people buy and consume more food items like fruit and ice-cream and more beverages. Analyses performed on retailing series produced evidence to support this hypothesis. These fluctuations in consumption should produce demand-led changes in the manufacturing sector, which we investigate here. The economic series selected for analysis is monthly values of the seasonally-adjusted Index of Industrial Production for the FDT sector over the period 1972–1995 inclusive (Central Statistical Office, 1972–1996). The seasonal adjustment involves removing the intra-annual fluctuations which recur every year.

4.2.2. *Methodology*

Like the fuel consumption series discussed above, the food, drink and tobacco series exhibited a gradual upward trend with time, but when a linear trendline was fitted the residuals from this line were found to be too systematic. Two techniques were therefore applied. First, a 13-point unweighted moving average was used to smooth the series and the anomalies were taken to be potentially related to fluctuations in weather conditions. Second, the index value for each month was compared to the mean value in the previous three months, and the differences were then analyzed in association with the weather variables. Whereas the first method isolates the residuals from the longer-term smooth trend, the second identifies the change relative to preceding, shorter-term, output levels. Both were found to produce values which are apparently randomly distributed with no obvious trend or cyclicity. Correlation and regression analyses were performed by month, for all twelve months, using these two series as the dependent variables and three weather variables as predictors: Central England temperature (CET), England and Wales precipitation (EWP) and England and Wales sunshine (SUN). Both same-month and lagged (up to eleven months) predictor variables were used. The stepwise regression analysis was performed using the SPSS statistical package.

4.2.3. *Results*

Comparing the results of the two approaches – the anomalies from the running mean (FDT1) and the differencing method (FDT2) – the weather variables explained a higher proportion of the variation in the FDT1 series than in FDT2. The FDT1 models included six months in which final adjusted R^2 was $> 30\%$ compared with only three such months in FDT2. Therefore, we confine the description of the results here to the FDT1 series. All three weather variables were important predictors, but temperature was most frequently significantly correlated. The relationship with temperature was always negative in the last three months of the year, but when

TABLE VI

Weather predictors of food, drink and tobacco production

Month	Stepwise regression selected weather variables[a]				Final adjusted R^2	CET only	Final adjusted R^2
Jan	None					None	
Feb	SUNDEC	SUNOCT	SUNAUG		0.50	None	
Mar	None					None	
Apr	SUNAUG[b]	EWPJUN	CETJUN		0.65	CETJUL	0.26
May	None					None	
Jun	CETMAY				0.15	CETMAY	0.15
Jul	CETJUL[b]	EWPMAY	EWPAUG[b]		0.46	CETJUL	0.19
Aug	SUNDEC	SUNMAY	CETJUL	CETMAY	0.59	CETJAN	0.17
Sep	EWPJAN				0.21	None	
Oct	EWPDEC	EWPNOV			0.33	CETMAY	0.14
Nov	CETMAR	SUNOCT			0.32	CETMAR	0.18
Dec	CETMAR				0.26	CETMAR	0.26

[a] Weather variables are shown in the order in which they are included in the regression analysis.
[b] These predictors were used to estimate the monetary impact of the high summer weather.

temperature appeared in other months it was always positively correlated with production. The weather variables chosen by the stepwise procedure for FDT1 appear in Table VI. Lags of almost every duration – ranging from one to eleven months – were evident in the regression analysis. A same-month relationship was found for July temperature only, perhaps because of a short lead-time on hot weather items such as ice cream.

One of the primary aims of the study was to examine the economic impacts of the hot summer of 1995, in particular July and August. As shown in Table VI, weather variables from these months were chosen as leading predictors for the FDT1 in the months of April and July only. We present here the results from April and July regression models with respect to the impact on this sector of the summer of 1995 and the hot summers of 1975 and 1976.

The FDT1 regression equations were re-calculated for April and July. For April FDT1, only August sunshine was used as a predicator variable. The correlation between these two variables is $+0.59$. July FDT1 was predicted by July CET alone $(r = +0.19)$. These equations were then used to estimate the weather-related changes in production linked to the anomalous summers of 1995, 1975 and 1976. The predicted values for the selected months based on the model results, are shown along with the actual values in Table VII. The predicted weather perturbation for July 1995 manufacturing was $+0.38$. The actual perturbation from the norm $(+0.63)$ is greater than the predicted perturbation in July, but it cannot be assumed

TABLE VII

Perturbations from normal index of production of FDT due to 1995 July and August weather

Month	Production relative to the running mean	
	Actual	Predicted
July 1975	–1.22	0.00
July 1976	+0.41	+0.41
July 1995	+0.63	+0.38
April 1976	+1.56	+1.06
April 1977	+0.93	+1.67
April 1996	+1.10	+2.42

FDT: food, drink and tobacco production.

that all of this would be weather-related impacts. The predicted weather perturbation for April 1996 production was $+2.42$, but the actual change was only $+1.10$. Note that the predicted value for April 1996 represents an independent valuation of the regression model, since this month was not included in the constructed series. The predicted weather perturbation for July 1975 was 0.00 whereas the actual perturbation was rather different at -1.22. For July 1976, however, the predicted and actual perturbations were identical at $+0.41$. The predicted weather perturbations for April 1976 and April 1977 were $+1.06$ and $+1.67$ and the actual changes were $+1.56$ and $+0.93$ respectively. We estimate that the predicted perturbations to the production index for July 1995 and April 1996 can be valued at +£5 million and +£33 million, respectively, whereas the actual perturbations represent gains of £8 million and £15 million. Thus, the models for July 1995 and April 1996 suggest an increase in output in response to hot sunny summer weather.

4.2.4. *Discussion*

The findings here that production of food and drink increased in warmer weather are broadly consistent with observations of weather-related increases in fruit and vegetable retailing. Because manufacturing is a major part of U.K. output (see Figure 1), perturbations in this sector often have more important ramifications for the economy than do the more obvious impacts on sectors such as agriculture.

It is clear that the relationships between climate and production are much less straightforward than those between climate and energy use. Both positive and negative correlations are found for the same climate variable in different months. Lags are often long, to the point where it becomes difficult to see them as realistic. Such characteristics must throw doubt on the validity of the results. The July model, with a zero lag in the predictor variable, must be more persuasive than the April model, with a nine-month lag. Further research, concentrating on extraction of time series of sufficient length to permit proper validation of the regression models, is required before any of these models can be regarded as a reliable portrayal of climate-production relationships.

5. Summary for Other Sectors

Impacts related to tertiary sectors including manufacturing and retailing, buildings and tourism are readily valued because these series are expressed as output, sales or expenditures. These activities, however, often involve lags and short-term cycles that complicate the identification of the climate-economic relationships. Impacts related to human risks – health, crime, and secondary fires – can – affect human well-being, but these effects cannot be readily assessed in monetary terms. The approach taken to analyze the remaining activities is briefly described below. The major findings on quantified changes in tertiary activities in the 1995 year compared with the longer series are summarized in Table VIII and additional details on data selection, methodology, valuation approach and implications of results are provided in sector chapters in Palutikof et al. (1997).

5.1. MANUFACTURING AND RETAILING

5.1.1. *Manufacturing*

Using the identical approach to the analysis of manufacturing of food, drink and tobacco described above, we examined the weather-sensitivity of the clothing and footwear industry from the Index of Industrial Production recorded in the *Monthly Digest of Statistics*. For this manufacturing series as well, we looked for correlations between weather variables and both residuals from a 13-pt running monthly mean (CF1) and the difference with the current month and mean production in the preceding three months (CF2). We found more significant correlations with CF2. Temperature is the least common weather predictor and EWR is most commonly associated with both series but the sign of the EWR relationship varies. January and November in particular have a high proportion of the variance explained by weather variables (CF2). We did not assess the economic impact of high summer weather on the clothing and footwear series because neither July nor August weather appear as leading variables.

5.1.2. *Retailing*

Five time series were selected from the *Monthly Digest of Statistics* (CSO, 1973–1996) as a reasonably representative sample of markets that may be weather sensitive: volume retail sales, clothing and footwear retail sales, fruit and vegetable retail sales (all in Great Britain), wine consumption in the U.K. and beer production in the U.K. Long-term trends were removed by fitting linear trend lines, polynomials or moving averages (whichever gave the best fit), and the residuals were

TABLE VIII

Impacts on tertiary activities and human-risks

Sector/activity	Estimated consumer/organizational expenditures (£ million)
Retailing (total sales)	–£87
Fruit and vegetables	+£24
Clothing and footwear	–£383
Manufacturing	
Food, drink and tobacco	+
Construction	No net change identified
Building insurance	
Subsidence	+£150–200 (insured losses)
Burst pipes	–£50–125 (insured losses)
Tourism	–£239
	Change in incidence
Health	
All-death rate	–9 deaths/day actual
Food poisoning	–11 deaths/day model fits
	£27 mil. Estimated added expenditures related to food poisoning
Behaviour	
All-crime rate	?
Sexual offences	+115 incidents
Fires (outdoor)	+54% from 1994

subjected to further analysis. Lagged climate variables for one and two months were considered for the total retail and clothing footwear series and lags of up to eight months were considered for the other series. In addition, the difference between the value of CET, SUN or EWR in the current month and in the previous month and, the difference between the current month value of each weather variable and the value for the same month in the previous year were considered. Stepwise multiple regressions were subsequently performed. The total retail market is observed to be more sensitive to temperature than sunshine, with rainfall playing the least important role, and the associations are strongest from December to April. Comparing results for the different economic series, the strongest impact due to the 1995 weather anomaly was found for the clothing and footwear series, with net losses over the 12-month period estimated at £383 million. In the food sector, large gains were found for beer and wine production, which were valued at around £134 million, and smaller gains for fruit and vegetables sales, at around £25 million over the 12-month period (Agnew and Palutikof, 1999).

5.2. TOURISM

Three series that relate to domestic tourism were investigated: bed occupancy rate, within-U.K. expenditure and number of trips. All of the series were extracted from *Tourism Intelligence Quarterly* which is prepared by the Economics Unit of the British Tourist Authority and the English Tourist Board for the period available which was 1989–1995 for expenditure and number of trips in the U.K. and 1979–1995 for hotel bed space occupancy in Great Britain (BTA/ETB Research Services, 1996). Because the data series are short, the relationships were analysed on a quarterly basis, so that a one month lag in the climate variables from January, February, March is December, January, February, a two month lag from January February March is November, December, January, and so forth. Stationary series were obtained by taking the residuals from a moving average or polynomial fit or by calculating the difference between the current and previous month. All series were found to be less responsive to weather fluctuations in summer than in other seasons. The bed occupancy rate and the number of trips showed a clear, immediate and understandable relationship with weather. When the weather is fine and sunny, both series rise. The relationship between expenditure and weather is more complex and less easy to understand: domestic expenditure falls around six months after a spell of warm weather, and changes in expenditure as a result of hot weather in 1995 is estimated at around £239 million. However, further investigations of the apparently strong but long-lagged relationships between weather and tourism expenditure are needed.

5.3. BUILDINGS

5.3.1. *Construction*

Indicators of activity in the building sector tend to be available at the quarterly level only, so we selected the only relevant variable available at the monthly level – number of bricks produced, as reported in the *Monthly Digest of Statistics* for the period 1972–1995. The same methods were used to prepare this series for regression analysis as used in the manufacturing series described above. It is found that weather predictors are more likely to explain the variance in CON1 than in CON2. Based on the regression results, we hypothesize that July and August temperatures have no discernible influence on brick production over this period. While variation in production is correlated with weather in some months, it is suggested that little long-term impact on brick production is observed because unusually high demand in one month is matched by a reduction in demand at other times of the year.

5.3.2. *Property Insurance*

Two types of weather-related impacts on buildings were investigated: damage from shrinkage of clay-rich soils and damage from burst pipes due to freezing conditions. Statistics on insurance claims from both types of damages were obtained from the Association of British Insurers. At the time the analysis was completed, the recorded subsidence claims in 1995 were similar to that of 1989, but were clearly low compared with the actual number of claims due to delays in making and recording claims. The relationships were explored through correlation analysis nonetheless. The mean values for all summer months CET and EWR were correlated with subsidence-related claims, using current-year and previous-year values for the weather variables. Indeed, no significant correlations were obtained. However, a simple comparison between 1995 gains and losses from the previous year suggest that losses in 1995 were up by £197 million for subsidence-related damage and down £47 million for burst pipes.

5.4. HEALTH

The fluctuations in all-cause death rates and in food poisoning notification rates were examined. Monthly data for deaths from all causes and officially notified cases of food poisoning in England and Wales were taken from the Registrar General's *Weekly Returns* and *Updates* for the period 1975 to 1995.

5.4.1. *Mortality*

Multiple regression analysis was used to model the relationship between death rates and influenza deaths, Central England mean temperature and mean temperature squared. These variables were chosen because the relationships between death rates and influenza epidemics in the U.K. are well established (Langford and Bentham, 1995) and because a quadratic function for temperature allows the modelling of a relationship in which daily death rates might rise both in cold weather and during heatwaves. These predictors were found to explain 87% of the variance in the dependent variable. In order to control for confounding factors that also vary seasonally, dummy variables were created to represent the twelve months of the year and the regression model was used to predict death rates for every month. It was found that as temperatures increase, all-cause death rates decline, but there is an indication of an upturn in the very hottest months, suggesting an adverse effect from the most extreme heat waves. As might be expected, the largest reductions are predicted to be in the colder months of the year when higher temperatures would be likely to reduce the toll of excess winter deaths. In 1995, an unusually mild February saw fewer deaths than usual for the time of year, but actual death rates in July and August were above normal by 5% and 1% respectively and were broadly in line with the model predictions. If the patterns identified held constant into the future, a warmer climate would lead to additional deaths in extreme summer heat waves but these would be more than offset by the decrease in winter mortality.

5.4.2. *Food Poisoning*

One of the most important health problems in Britain associated with high temperatures is food poisoning (Bentham and Langford, 1995). The same statistical modelling approach to that described for mortality was used for the assessment of temperatures on the incidence of food poisoning. In order to focus on the month to month variations rather than the dramatically increasing trend over time, the data were detrended by dividing the original data by a regression estimate based on a time index (month order) and time index squared. A regression analysis showed that mean temperature of the same month and the mean temperature one month earlier explained 72% of the variance in the detrended food poisoning notifications. On the basis of the model results, a particularly serious food poisoning problem might have been expected in 1995, however while recorded cases for July and August were higher than normal for those months, they were somewhat lower than predicted levels. The economic impact of higher food poisoning incidence was assumed to be about £128 per case based on a previous study adjusted for inflation (Roberts et al., 1989), summing to £29 million for the year.

5.5. BEHAVIOR

Possible impacts of warmer weather on behaviour identified from the existing literature include an increase in violent suicide (Maes et al., 1994), greater incidence of violent crime and possibly property crime (Field, 1992), and higher levels of sociability (Robbins et al., 1972). We sought to investigate the general relationship between crime and weather by correlating detrended crime data with the climate variable deviations using two categories of crime data compiled by the Home Office of England and Wales and the Scottish Office – total notifiable offices and sexual offences by quarter over the period 1976–1996 (Home Office, 1996 and Scottish Office, 1996). The upward trend in the data was removed and the crime data were correlated with mean quarterly CET, EWR and SUN. The analysis did not reveal significant correlations. Month to month correlations with CET were pursued and a significant correlation was found for the month of March only. A plausible explanation is that a significant change in the total level of crime recorded, beginning around 1989, may explain the lack of corrrelation observed in the 1990s. For the sexual offences series, significant correlations were found between these data for England and Wales, and all of the weather variables (CET: +0.63, EWR: –0.24, SUN: +0.61). Elevated levels of recorded sexual offences based on the deviation between expected and actual crime incidence were found for the warm years of 1976, 1989 and 1990 but not found for 1995. The economic impact of changes in criminal activity was not valued for this section.

5.6. FIRES

Data on the number of outdoor fires occurring in England and Wales each year over the period 1984–1995 were used to analyze the sensitivity of secondary fires to weather (Government Statistical Service, 1996; G. Goddard, pers. comm.). Correlation analyses using summer climate variables (CET (J+A), CET (J+J+A), EWR (J+J+A), EWR (J+A) from the current and previous year as predictors was carried out. Correlations with the previous year were found to be lower and not significant but all correlations from the same year are highly significant at +0.84, +0.76, –0.87 and –0.76 respectively. The change in the number of fires between 1994, which was an average summer, and 1995 in England and Wales was large (+54%). Inspection of the longer-term patterns shows that an upward trend is apparent in the number of fires since around the early 1980s, and the inhomogeneity was deemed too serious to justify detrending or making a comparison between the 1976 and 1995 anomaly. Although no figures could be obtained to demonstrate costs of fire control or property damage, the costs of fire fighting in 1995 must have been substantial, and it is likely that additional resources would be required for fire fighting in a warmer world.

6. Seasonal and Decadal Sensitivities to Climate Variability

First, we looked at the relative sensitivities of the economic series to unusual warmth in the summer and winter. This could be done simplistically by comparing the impacts of the warm winter of 1994/1995 with those of the hot summer of 1995. However, a more systematic approach is to look at the regression equations predicting measures of economic performance from climate variables. Since these were generally calculated for each month of the year, using current-month and lagged predictors, the power of the relationships and the predictors selected by the stepwise procedures give an indication of the relative importance of winter versus summer extremes.

Examples of sectors which show clear differences in their response to winter and summer warm anomalies are health and energy consumption (greater sensitivity to winter anomalies) and buildings insurance and fires (greater sensitivity to summer anomalies). For health, the reduction in deaths due to warmer conditions in winter more than offsets the increase found in the very hottest summer months over the time series analysed (1975–1995). In the energy sector, the regression equations linking energy use to same-month temperatures have much greater predictive power in the winter, fall and spring months. The same regression equations indicate that consumer savings due to a 1 °C temperature increase in winter are greater than savings as a result of a 1 °C increase in summer. On the other hand, losses to the insurance industry from subsidence-related claims due to dry summer weather are generally greater than those associated with winter burst-pipe damage, although pipe damage occurs more often albeit at lower unit costs. For the annual number of outdoor fires, the correlations with EWP and CET for June, July and August are both high and significant.

February and March appeared as important months in a number of sectors. They can be a key transition from cold winter to warmer spring weather, and variability in these months appears to affect a range of human behaviours. The weather conditions in February appeared as principle indicators for beer and wine production. February and March conditions are also important predictors of activity in food, drink and tobacco manufacturing, and the construction industry. The strongest correlation between temperature and total recorded crime was found for the month of March. Higher hotel occupancy corresponded with sunshine during the first quarter of the year.

Second, we sought evidence for long-term changes in the sensitivity of the British economy to climate extremes. This was possible because, for most sectors, time series of activity were extracted for a period from the early 1970s to the present day, thus including the notably hot summer of 1976. There are a number of reasons why changes in sensitivity may have occurred. Over a period of twenty years it is likely that technological advances and changes in the structure of the economy will have lead to changed sensitivities. Second, the increased frequency of hot summers in recent years (notable extreme summers since 1976 occurred in 1983, 1989, 1990 and 1995) may have lead to deliberate adaptations. Third, changes in management that are not climate-related may have the effect of altering sensitivities. With respect to the first cause, we find for example that in the energy sector the shift from electricity to gas as the principal fuel for domestic space heating in recent years has lead to a much greater sensitivity of domestic gas consumption to extreme summers. With respect to the second, there is no clear evidence of adaptation in the sectors considered here. In the U.K. it is the agriculture and water sectors that show the strongest evidence of adaptation already occurring. With respect to the third cause, an example exists in changes in fire management, such as the ban on stubble burning imposed in the mid-1990s, which has reduced the incidence of outdoor fires in some regions (Baker, 1998).

Arriving at a proper quantification of changed sensitivities is not a simple matter, largely because the characteristics of individual hot summers differ. A possible clue to changing sensitivities may be obtained from the regression equations which were constructed for most sectors to link climate variables to measures of economic performance. In these equations, the economic indices are expressed as anomalies from the long-term trend, in an attempt to isolate the climate-related signal. We may argue that, if the economic measures are becoming less sensitive with time, the ability of the regression equations to predict the anomalies from the long-term trend will lessen, and so the differences between the observed and predicted residuals will increase (and *vice versa*). This hypothesis was tested in the retailing sector, where the equations are constructed from a choice of same-month and antecedent-month climate variables (using stepwise procedures), and so should be able to take into account such contrasts as existed between the dry winter preceding the 1976 summer and the wet winter preceding the 1995 summer. The August residuals are plotted for three series – clothing and footwear sales, fruit and vegetables sales and

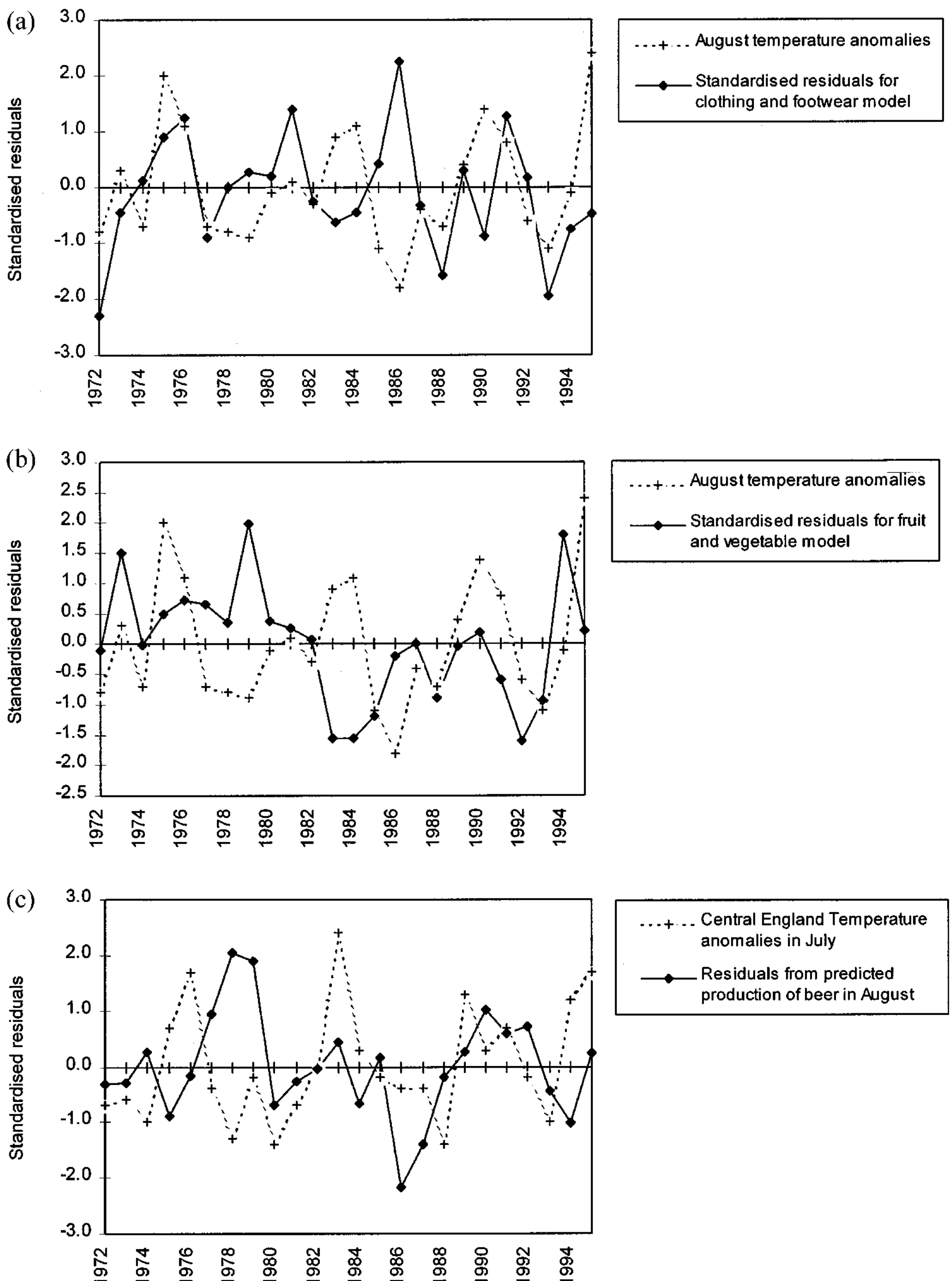

Figure 3. Plot of standardized residuals for the regression model in August for clothing and footware sales, fruit and vegetable sales and beer production. These residuals represent the fit of the model; the lower the residuals the more accurate the model.

beer production, in Figure 3. They fail to show any persistent trend in variability with time (although in fact the residuals are greater in 1976 than in 1995 for all three series). This must be either because no trend exists, or because the influence of non-climatic effects is obscuring such trends.

7. Implications for Economic Impacts of Global Warming

This study has been confined to observed changes in human activities during a discreet twelve-month period of warm weather. In this respect, it differs from the climate change damage cost studies that have been completed to date. One study of potential climate change impacts in the U.S. Great Plains economy applied assumptions of a future economy to historic (1930s) climate change in the MINK region (Missouri, Iowa, Nebraska and Kansas) (Rosenberg et al., 1993). Research on potential changes in Gross World Product due to climate change in the mid-21st century has relied on scenario assumptions for future economies, populations, technological applications and climate (e.g., Cline, 1992). As an historical analogue, avoids mixing assumptions of baseline economic activities, climate and systemic response.

Accordingly, because economies are dynamic and no two short-term climate anomalies will be the same, we believe that there is no reasonable way to project the economic costs of a single climate anomaly to some future period. That is, our results are not directly relevant to the study of expected climate change impacts in the U.K. in the next century. However, because the year examined in this study was such a striking anomaly, we may make some tentative links between the results and the economic impacts from longer-term climate change.

The measured changes in economic impacts by sector in 1995 may seem rather high (i.e., 1–6% in selected output categories) within the context of projections of economic damages from global warming as estimated in the recent economic literature. Best-guess central damages from global warming from a $+2\,^{\circ}$C warming centre around 1.5–2.0% of world GNP (IPCC, 1996). We may venture that, given the same valuation assumptions, we would expect average losses to U.K. GDP to be less than the proportionate losses to Gross World Product, given that the U.K. is not especially vulnerable to devastating natural hazards such as hurricanes, coastal inundation and desertification compared with many other regions (IPCC, 1996a).

Direct comparison between the IPCC (1996b) estimates of impacts on world GNP and the results from our study should be avoided because the studies cited in the IPCC's Second Assessment Report involved average welfare impacts whereas this study addressed economic impacts of one anomalous year. The relevance of the 1995 analogue results to climatic change is less for sectors and activities where longer-term adaptation is likely to take place and thereby either add to or detract from shorter-term costs (<2 years) as assessed here. The statistical approach employed in this study, if extrapolated to assess longer-term warming, would tend to overestimate the future economic impacts on those activities where the opportunity for adaptation is considerable and not costly to implement, e.g., crop substitution in agriculture. Additional research would be required to project future impacts for those activities where adaptation would be costly but deemed necessary, so that implementation would be gradual and on a long time scale. For example, the statistical approach does not easily track costs such as adaptive investment in new reservoir construction made long after an unusually dry period. On the other hand, the analogue is strong for impacts where little or no institutional adaptation is required, e.g., household consumption of heating fuel, or for activities where adaptations are unlikely to be implemented because of cost or other difficulty, e.g., outdoor fire occurrence. For these activities especially, we believe that empirical analysis of actual impacts of weather extremes can lay the basis for a better understanding of the potential impacts of climatic change.

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