The Climate–Energy–Economy Link

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World economy changes from time to time. We all know that. National economies follow suit; some would say that the bigger nations, especially the USA, can induce global changes. Personal economies respond accordingly.

As we move into the mid-1980s there is talk of our climbing out of the current world depression, which is generally acknowledged to have begun with the recession led by the energy crisis of 1973. That crisis is history. It was promoted by the war in the Middle East and resulted in a dramatic increase in oil prices worldwide.

The economy–energy link would seem to be fairly conclusive from this evidence. This relatively short-term example would appear to suggest that mankind is able to influence fairly strongly its destiny, at least as far as inducing its economic wellbeing—or, in the case of the recent apparently energy-led recession, economic ills. That is to say, if energy supplies can be maintained at an economic level by diplomatic and political means, global economy will blossom. However, the record of this happening is not good. War can disrupt the balance, as we have seen and, in any case, should we necessarily accept the close primary association of economy and energy quite so readily? For instance, how long has it been going on? More fundamentally, why has it been going on? Is it really as simple as it seems?

This paper sets out to explore these questions in the light of the current vogue for considering long-term economic cycles. It broadens the issue to include industrial production and agricultural factors which introduce a further element into the equation—climate change. Finally, despite the general weight of literature expressing a contrary opinion, it is concluded that the economic machine is indeed climatically-controlled and that the provision of energy is, in fact, a response and not a driving force. In turn it is illustrated that a climate-forecasting model is available to permit considerable confidence in planning to accommodate future economic trends and the provision of energy requirements for them.

1. BACKGROUND

The approach to climate forecasting described in this paper is, paradoxically, rooted in the search for better methods of investigating the seabed to assist the offshore energy industry. In order to build offshore structures for the exploitation of submarine hydrocarbon reserves and to transport these reserves to shore it is necessary to have information about the mechanical properties of the seabed. The installation of heavy structures may require local information to depths of many tens of metres below the seabed, whereas pipelines or anchorages can be placed on the strength of information down to only a few metres of depth but over a large area of the seabed.

It has long been recognised that the act of sampling the seabed for later laboratory investigation inherently induces changes in the very mechanical properties that it is designed to secure. First, the seabed is remote from the surface shipborne drill rig from which the sampling device is controlled so that the action of sampling is more distant than an equivalent procedure on land; this therefore provides the greater opportunity for disturbance in-built in most remote activities. Second, and perhaps more importantly, the recovery of the sample to the surface allows the total pressure on the sample to be reduced by the equivalent of the hydrostatic head of water at its *in situ* position; this allows any entrained gas to expand with the resulting disruption of the microstructure of the sediment sample. In either case, the disturbance induces an unknown amount of change to the original *in situ* mechanical properties of the sample. Consequently the subsequent laboratory-testing of

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the samples can give misleading results. However, this overall programme is a fairly standard site-investigation procedure despite its potential inaccuracies—overall, a very unsatisfactory state of affairs.

In an effort to overcome these problems a variety of methods of acquiring mechanical properties of the seabed indirectly was explored. Some of these were aiming to acquire the necessary information without recourse to sampling, thereby avoiding the disturbance issue. These can be divided into two camps: seabed probing and geophysical sounding. Other methods proposed to take advantage of correlations between easily-determined index parameters of sediment from disturbed samples and the more costly and difficult to acquire undisturbed mechanical data. One such method sought to correlate lithological indices (particle size distribution) and geotechnical indices (plasticity range, etc.) with undisturbed mechanical properties; another successfully attempted the correlation of population distributions of micro-organisms once living on the seabed with the elusive mechanical characteristics. However, it was the pursuit of a possible correlation of oxygen isotope data with mechanical properties that eventually led to climate forecasting—just as well, since the required correlation was not forthcoming.

The accidental nature of this development is amusing. In fact, as all climatologists know, oxygen isotope records from borehole profiles such as those into the seabed relate to past climates: the lower the oxygen isotope value, the higher the global temperature at the time the sediment was laid down. However, the author did not know this when the data in question were discovered in a volume of the Deep Sea Drilling Project (DSDP) reports (Shackleton and Cita, 1979). His interest in the published variation of the isotopes down to a depth of 560 m below the seabed in the North Atlantic was at that time merely to seek their correlation with mechanical data.

The subsequent derivation of a deterministic equation to describe the variation of climate during the whole of the 7 million year period of sedimentation at that site and, indeed, back through geological time to about 3000 million years (two-thirds of the commonly agreed age of the Earth) is recorded at length by Denness (1981, in press, *a–c*). Those articles identify a mathematical model comprising a sine series of ever-halving periods with amplitudes simultaneously reducing by a factor of 0.84 from a fundamental period traceable to several thousand million years down to a matter of a few years of climate variation. There the model has been substantiated by comparison with measured proxy climate data from a wide-ranging literature review. However, none of the data used to derive the model was of an economic or energy nature, so that the comparisons to be drawn here between the output from the model and these types of data are a genuine test of the correlations.

2. CLIMATE

The mathematical model which describes the variation of global temperature within the ranges of measurement accuracy of the observed proxy palaeoclimatic data available from the literature is contained in equation (1):

$$G(t) = \sum_{n = N(T)}^{\infty} A(T)\, a^{n} \sin b^{1-n} \pi\, (t/T), \qquad (1)$$

zero registered at time T_0

where $G(t)$ is a time-based climate index, $A(T)$ is the amplitude of a reference periodicity T, $N(T)$ is the reference integer for periodicity T, a and b are absolute constants, here taken as 0.84 and 0.50, respectively, n is an integer, i.e. the reference number of a particular sine component and t is time in years.

In each of the time series figures which follow, the output from this equation has been processed by a smoothing technique to provide a thick continuous line for the model of the same order of sensitivity as the comparative recorded and interpreted data concerning energy and economics. The technique employs a moving average of 100 data points within the 600 such points output from the equation for each figure. To do this to the full length of the time-scales shown, it was, of course, necessary to encompass 50 data points beyond each end of these scales. This embraces output extending into the future for 10% of the time-scale covered in each case. That the trend from

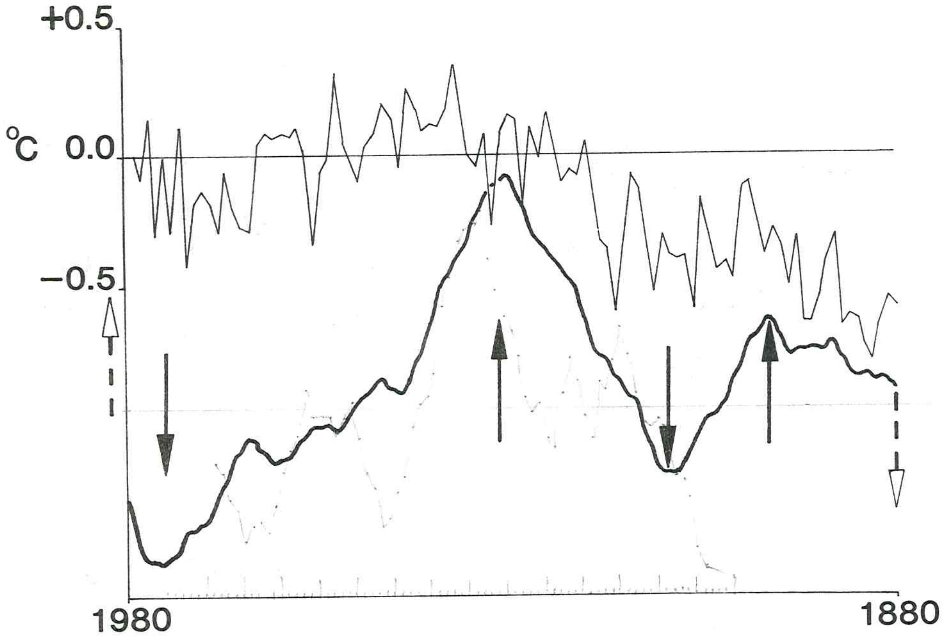

Fig. 1. Variation of recorded northern hemisphere temperature and climate model since 1880: (——) model; (——) northern hemisphere temperature.

the model is nevertheless reasonably consistent with those of the observed series is all the more encouraging in relation to its forecasting potetential, i.e. there is a forecasting element in these figures, albeit that they extend only to 1980.

Figure 1 superimposes the record of northern hemisphere annual temperature anomalies reported by Jones and Wigley (1980) on the climate model. The trends of each are emphasised at their maxima and minima by the arrows and are seen to be in good agreement over the period since 1880, when the measured record began. In this and all later figures which portray the climate model, the vertical scale refers to the measured data while the model itself is not quantified in amplitude, it being sufficient here to adjust its vertical scale to match that of the measured data thereby emphasizing the cyclic coincidences between model and measurement. It should also be noted that in all these figures the future is to the left.

Remaining with climate it is appropriate to turn to Figs 2 and 3, which are based on data in an article by Wigley *et al.* (1980) and describe, respectively, the regional variation of precipitation and temperature induced by a rise in global temperature. It can be seen that while some regions of the world get wetter, others become drier. Similarly, different parts of the world experience different temperature changes as components in an overal global warming, some of them even becoming cooler.

Combining the information in Fig. 1–3 leads to the ability to reconstruct, approximately, regional trends of both precipitation and temperature throughout the twentieth century without recourse to local data. In particular it enables attention to be drawn to the distribution of both precipitation and temperature in the main occupied areas of the developed world during that time. Not surprisingly these are coincident with most of the major food-producing areas, in particular the mid-west of the USA, northwest Europe and Kazakhstan in the USSR. Here, then, is a potential climate–econmomy link via the agricultural connection. A simple, some would say simplistic, approach would suggest that, by analogy with the behaviour of growing plants in even an individual garden or field, the

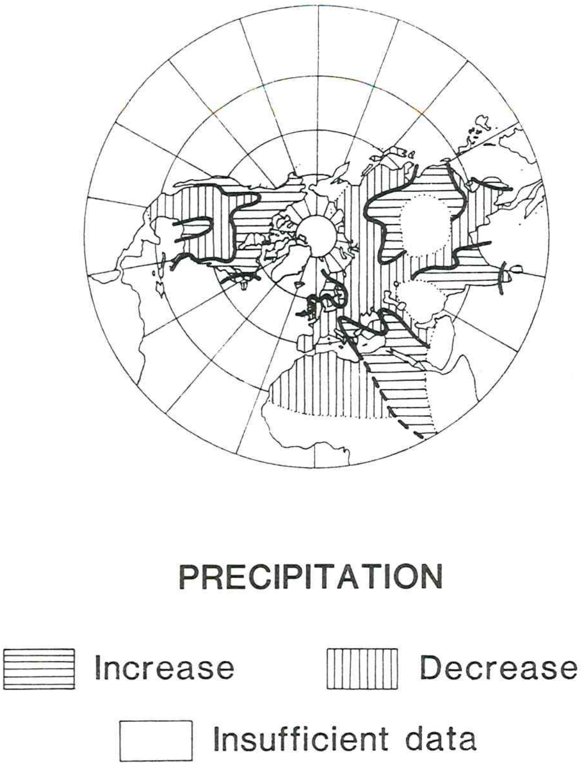

Fig. 2. Regional variation of precipitation in the northern hemisphere in response to global warming (after Wigley *et al.*, 1980).

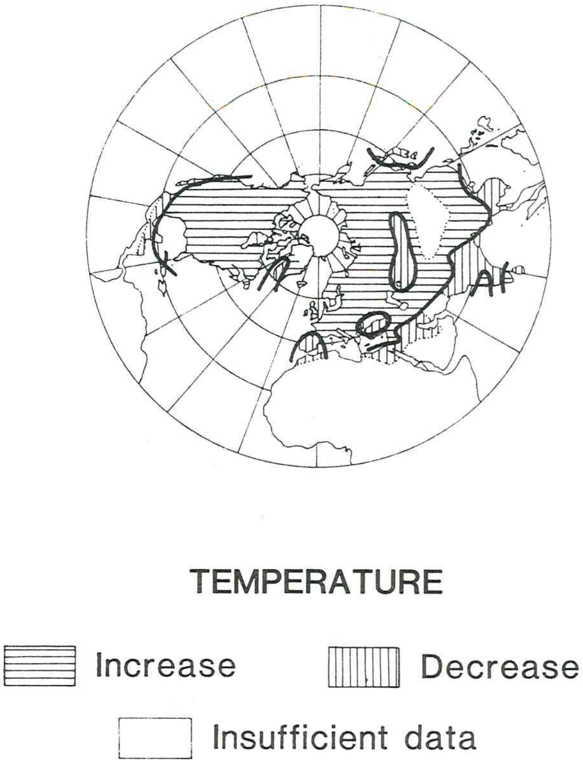

Fig. 3. Regional variation of temperature in the northern hemisphere in response to global warming (after Wigley *et al.*, 1980).

drier the food-producing parts become the less food they produce, or alternatively the more resources must be diverted into irrigation or green-revolution tricks to produce the same amount. As coincidence would have it, Fig. 2 illustrates that most of the food-producing areas exhibit the same response to global temperature change, i.e. they become simultaneously drier as the global temperature increases, and vice versa. The economic impact should be readily determined according to the simple view above. But is there indeed a correlation between global economy and climate?

3. ECONOMY

Figure 4 superimposes the trend of global economy on that of global temperature described by the mathematical climate model, which was seen from Fig. 1 to represent this temperature well for the twentieth century. The economic summary is taken from the Cleary and Hobbs (1983) interpretation of van Duijn's (1977) cycles, and is seen to be in general agreement with the global climate model with additional emphasis to the compatible maxima and minima again drawn by the arrows. The answer to the question at the end of the last section is therefore 'yes', at least as far back as the time of the ending of the so-called Little Ice Age (a period of several centuries of colder climate almost worldwide) in the middle of the last century. So there is a demonstrable association of historical economic data with the climate model, but does it extend back beyond the last century and does it match measured proxy temperature data?

Indeed it does. Figure 5 represents the climatic model by the now-familiar thick continuous line

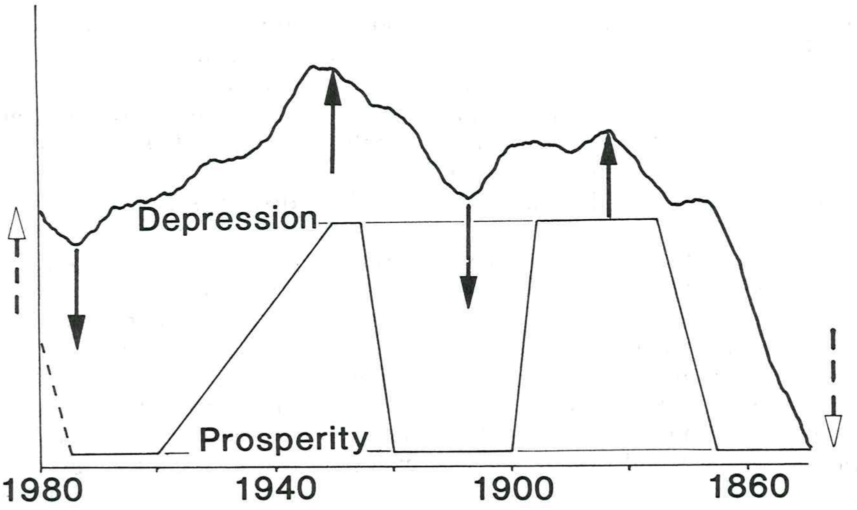

Fig. 4. Variation of gross Western economy and climate model since 1850: (——) model; (——) economy.

while superimposing the trends of two economic indicators back to the late thirteenth century for northwest Europe. Here we see that the economic indicators, the price of wheat in England and France measured in Dutch guilders per kilogram and reported by Lamb (1977) from unpublished work by L. M. Libby, exhibit generally similar trends (secular if not in magnitude) to those of the mathematically-modelled temperature. Particular attention is again drawn with the arrows to coincident maxima and minima. There is, however, one markedly abrupt anomaly—the trend in English wheat prices right into the twentieth century after about 1820. This falls dramatically while temperature, both global and in England, rises. The forecasting argument

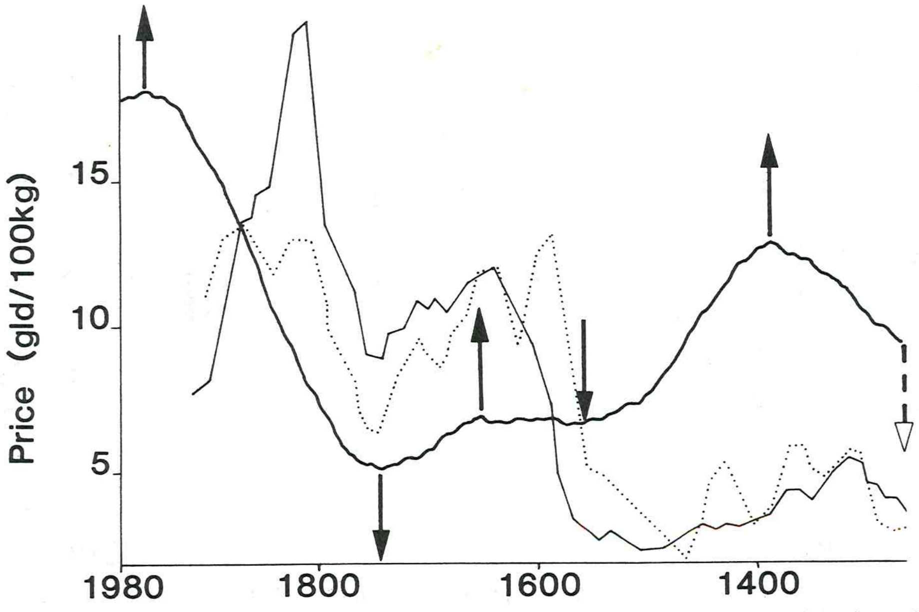

Fig. 5. Variation of price of wheat in NW Europe and climate model since 1280: (——) model; (——) England; (.....) France.

would not allow this, as a higher global temperature is seen from Fig. 2 to imply a drier England and should therefore lead to the production of less wheat, with a consequently higher price in a seller's market, as it had done for over 500 years until the early nineteenth century departure from the expected trend. Why then did this not happen?

The author is satisfied with an argument based on a consideration of colonial expansion. The British occupation of its colonies, especially Canada and Australia, was well under way by the turn of the nineteenth century. A colonial agricultural network was established and routes back to the motherland consolidated. Therefore, the shortfall in supply at home could be more than compensated for by exotic wheat. That, coupled with the export of adventurers to those very colonies thereby effecting a control on the hungry numbers left at home, seems to provide a convenient explanation of a peculiarity in the English data which does not manifest itself in that of its less-expansive southern neighbour.

But what of energy?

4. ENERGY

Energy supply comes within the same primary goods sector of the economy as does food. Rostow and Kennedy (1979), for example, provide an analysis of economic response to the failure to maintain the proper balance between supply and demand in this sector. A common argument has it that this imbalance can be sufficient to drive the economic machinery. But is that necessarily so, or are we possibly looking at a case of the tail wagging the dog?

Figure 5 has shown that at least one primary goods item, food, marches in time with climatic change—and has done so throughout an era extending back well beyond that of our modern sophisticatedly integrated international economies. Figure 6 now explores another primary item, energy. The thick continuous line again represents the climate model. The broken line indicates the global energy production growth rate (right-hand scale) prepared by Cipolla (1978), while the thin continuous line describes the data of Morrison (1982) relating to the variation of American household energy consumption measured in millions of British Thermal Units during this century (left-hand scale). The mean linear decrease of 1.05 million BTU/year since 1900 indicated by Morrison has been subtracted from the raw data before plotting with respect to 1900 consumption. Generally there appears to be

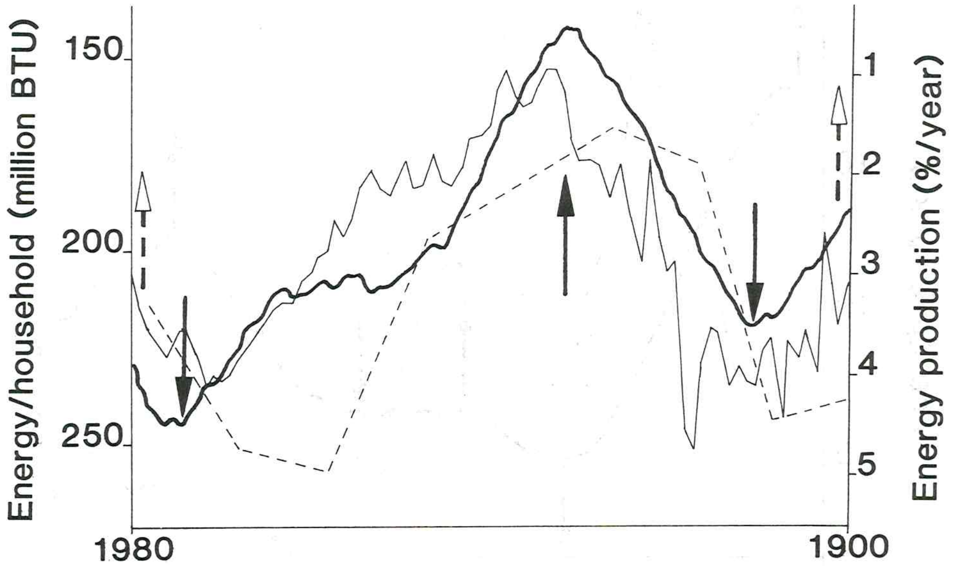

Fig. 6. Variation of global energy production growth rate and USA household energy consumption (reduced) compared with climate model since 1900: (——) model; (——) US household energy; (---) global energy growth rate.

a marked similarity in the trends, especially that of the energy used in households in the USA. Here, then, are both national and global energy records in step with the climate model.

Let us consider a possible explanatory mechanism. Instead of adhering to the supply-and-demand model of human incompetence documented so well in the economic literature, let us consider a more basic physical driving force—climate. Figure 6 shows that energy consumption goes down as global temperature rises. Figure 3 has already shown that a global temperature rise implies an increase in temperature for almost the whole of the most-densely populated parts of the USA. Therefore, for space heating alone it seems logical to suppose that less energy will be required in the USA when the world as a whole is warmer: that is reflected in the observation of Fig. 6. The precise correlation may be confused somewhat by other diversionary uses of energy, such as for entertainment purposes and air-conditioning, but is nevertheless apparently strong.

For the world as a whole, we see a generally similar trend in the energy production curve in Fig. 6 to that of global temperature increase, i.e. as global temperature rises, so global energy production decreases, though the relationship is less convincing than for the national data of the USA. We could attempt an explanation on the basis of limited energy data at too coarse a secular interval but this may not be necessary in view of the additional comment available from Fig. 3. There we see that Japan, one of the Western World's most prolific energy users, experiences cooling while the rest of the West and the world as a whole become warmer. Perhaps that alone is sufficient to account for the less-convincing comparison of global energy production and climate: we could, perhaps, look deeper at the Japanese issue and Fig. 6 in relation to the slight phase shift between the model and the observations, but that would introduce another element beyond the scope of this article.

5. INDUSTRIAL PRODUCTION

The only major item in the primary goods sector not touched upon here so far is that of raw materials: this is simply because no such simple mechanism can be expected to exist to link it to climate, as is instinctively the case from the everyday experience with food and energy production. However, coupled with the other primaries, albeit climatically inert in itself, it completes the commodity range which supplies industry. We should thus expect industrial production to be captivated by the rhythm of climate, even though diluted by this climatically-insensitive package within its otherwise climatically-dependent primary input.

Figure 7 returns to the time-scale of Fig. 4 to show the climate model alongside a dotted curve of smoothed data prepared by Kucztnski (1980) to describe the variation of industrial production growth rate in the capitalist world. We immediately see that there is a striking general correlation between the two curves. The foregoing sections have provided the data which enable construction of the links.

6. DISCUSSION AND CONCLUSIONS

6.1 OTHER FACTORS

It has been shown that, at least from an empirical analysis, there appears to be a fairly strong link between global climatic variation and both global and national economies. Mechanisms have been explored in an attempt to explain the connection: these have embraced primary goods, in particular energy and food, and economic indicators in the industrial and consumer sectors. Above all, an attempt has been made to restrict the analysis to a very simple form.

The influence of war, innovation, monetarism and other political and social issues have been omitted, yet the gross correlations with climate are still apparent. It would now seem logical to re-enter the analysis to examine whether the consideration of these other factors might allow a beneficial finer-tuning of the correlative model. While this would be an exhausting process, it should be considerably simplified with a mechanism for the removal of the primary influences on economic trends now available.

6.2 GEOGRAPHY

The economic data and their various component inputs available in most Western literature is

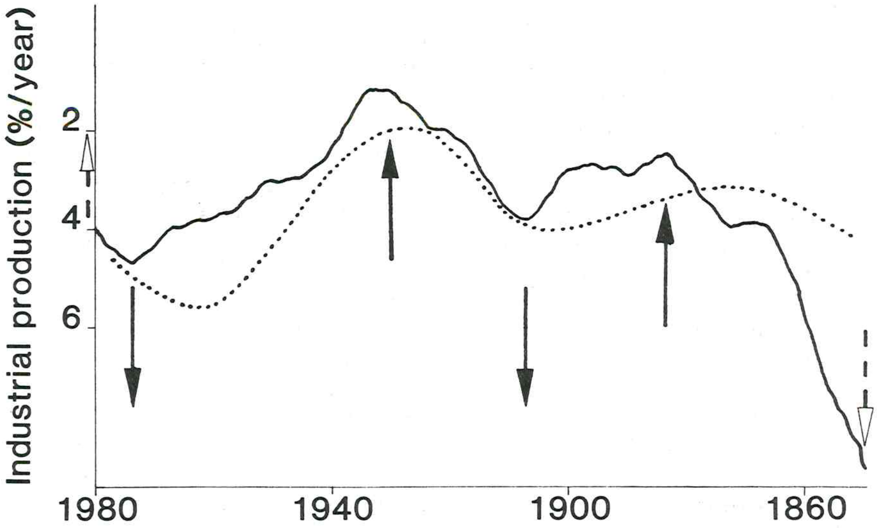

Fig. 7. Variation of capitalist world industrial production growth rate and climate model since 1850: (——) model; (. . .) industrial production growth rate.

restricted to the so-called developed world—even more, it is often restricted to the capitalist world of the northern hemisphere. To compound the problem it often specifically excludes data from the Indian subcontinent (with about 20% of the world population). We might benefit from considering the areas outside the perspective with which such a literature often leaves us.

Unfortunately, climatic data are barely more adequately available than economic. However, armed with empirical reason to do so, we might try to deduce a little more from the data in Figs 2 and 3 than has so far been attempted, even though they, too, are restricted primarily to the more-developed parts of the northern hemisphere. It is for the individual to home in on his favourite part of the world. If using these figures to do so he would do well to heed the warning of Wigley *et al.* (1980), who produced the originals, that these figures present "only a guide to broad scale patterns". Considerable refinements are still required before local interpretation can proceed with confidence; the trick at present is to estimate the division between broad-scale and local.

Inasmuch as the earlier analysis, particularly in relation to food and energy, relates to areas ranging from large to relatively small countries (USA, France, England) in addition to the 'global' view and yet was able to deduce consistent correlations, it would seem reasonable to suppose that reference to other parts of the world of similar size might be equally rewarding. There are two such places in particular which are covered by Figs 2 and 3 and yet are outside the main zones considered in the literature which provided the economic input to the analysis so far. These are China and India, with the order of 45% of the population of the whole world. What happens there?

Figure 2 indicates that the global warming, which induces a drier climate throughout most of the food-producing parts of the developed northern hemisphere, causes the majority of both China and India to become wetter. Figure 3 shows that as the world as a whole and most of the developed north in particular gets warmer, so does China, while India becomes generally cooler. In summary then, as the developed north gets warmer and drier, and consequently more depressed, so China also becomes generally warmer but wetter while India becomes cooler but wetter. In both cases they become wetter. As India is more than warm enough throughout the year for almost any form of food production and requires very little space heating, so such a reduction in temperature would not be seriously harmful. Hence both these countries would appear to be in a position to produce more food as the developed northern hemisphere produces less.

The economic implication would seem clear: as the developed northern hemisphere becomes depressed, so China and India prosper, and vice versa. Historical records are available to explore this further but must here be left to the pursuit of the reader. However, in the light of the earlier comments, readers are invited to be particularly wary of the interpretation of the influence of political intervention expressed in the literature both within and without those countries.

6.3 THE FUTURE

All the data referred to here relating to historical records of economic variables including the primary goods item, energy, relevant to the particular article have been shown to exhibit trends consistent with that of global temperature. Linking mechanisms have been explored. Global temperature, or at least that recorded for the northern hemisphere, has been shown to be described by an analytical expression given here as equation (1). That equation is seen to be time-dependent with no specific time boundary. Its output could therefore be extended into the future.

From the logic developed here, the forecast of future global temperature with its known implications for regional variation of temperature and precipitation could make available comments on the future development of the agricultural and energy industries and consequently their impact on regional and, indeed, global economy. At the same time the effect of the separation of the progress of the various integrated and isolated economies of the developed northern hemisphere from those of China and India could be reviewed to some advantage. No doubt the fullness of time will see whether the arguments constructed here are considered sufficiently promising to justify the operation of the model in forecasting mode.

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