A NOTE ON THE HISTORICAL INDUSTRIAL PRODUCTION OF CARBON DIOXIDE

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Abstract. The historical record of CO_2 emissions from industrial activity is reexamined. The overall annual growth rate has been about 3.5% but with wide variations due to economic fluctuations. It is unlikely that the total CO_2 production would have been greatly different had the major wars of the Twentieth Century been avoided.

This brief note will examine the record of CO_2 emissions, insofar as it can be inferred from the record of fossil fuel production. The past is an imperfect guide to the future but at present we have little else to guide us. The record used extends from 1860 to the present; up to 1949 it is from Keeling (1973) after which it follows the most recent update by Rotty (1981). Rotty has followed Keeling's techniques for the most part, adding estimates of CO_2 from the flaring of natural gas. This produces a very slight discontinuity in the record between 1949 and 1950 which can be ignored for the most

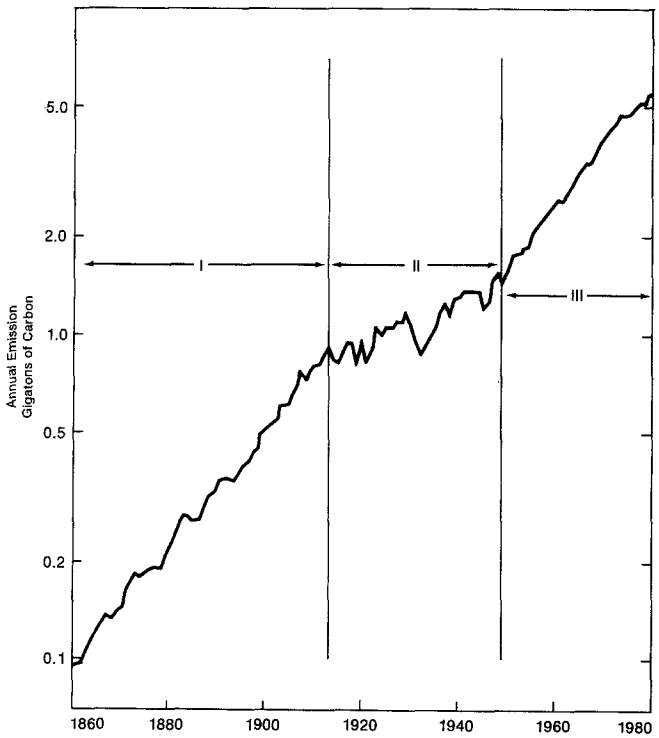

Fig. 1. Annual CO_2 production from fossil fuel combustion expressed as carbon.

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part. It is difficult to assess the overall accuracy of the numbers. Keeling estimated his analysis could introduce a bias of about 14% in either direction. As long as the technique is applied consistently, the reported year-to-year changes should be a good estimate of the actual changes in emission which is the subject of this note.

Figure 1 is the familiar plot of the estimated emissions since 1860 (see e.g., Rotty (1978)). It has been frequently interpreted as showing a 4.3% annual growth interrupted only by World Wars I and II and the Great Depression of the 1930's. This figure, 4.3%, was often used a few years ago to extrapolate future emissions. Assuming the partitioning of fossil fuel CO_2 among the reservoirs (air, ocean, biota) would remain about as it apparently has been since 1958 (when systematic observations began) this growth rate suggested the concentration would reach 600 parts per million (ppm) between 2025 and 2030. (Its present value is about 340 ppm.) The recent drop in annual growth rate (about 1.8% yr^{-1} for 1974–80) has led to lower estimates of future growth (see, for example, Rotty and Marland (1980)) and 600 ppm now projected to occur about the middle of the next century.

In the discussion that follows the annual percent change in fossil fuel carbon emission for year N is the difference between the emissions in year N and year N-1 expressed as a percent of the emission in year N-1. The average annual growth rate over a period of years is expressed as the arithmetic mean of the year-to-year changes over the period. The statistical properties of these year-to-year changes will be discussed without assuming they followed any preselected curve. To project emissions beyond the data requires some model, of course. It will also be convenient to divide the record shown in Figure 1 into three periods: Period I, 1860 to 1913; Period II, 1914 to 1949; Period III, 1951 to 1980. (The boundary between II and III was chosen to coincide with the slight shift in the record produced by the inclusion of natural gas flaring; 1945–46 could have been chosen almost as easily.)

Figure 2 is a plot of the annual growth rates and Figure 3 summarizes these rates in a histogram with 2% intervals. It is evident that the annual rates-of-change are quite variable; 21% of them are negative and nearly 15% are greater than 8%. Many of the low or negative annual growths can be associated with well known economic slumps (the Panics of 1872

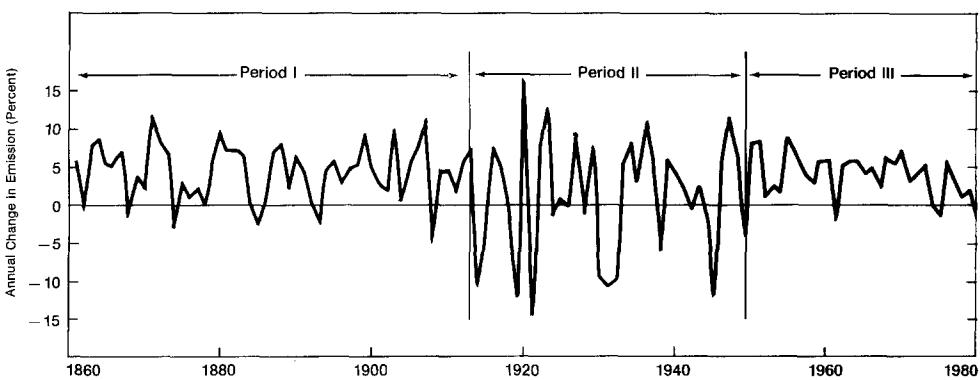

Fig. 2. Annual percent change in fossil fuel CO_2 production.

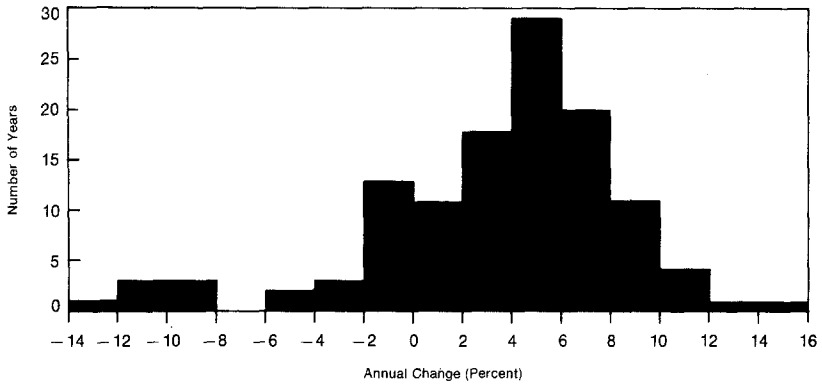

Fig. 3. Frequency distribution of year-to-year changes in CO_2 production.

and 1893 as well as the Great Depression, for instance). The quasi-periodic nature of the record of Figure 2 could reflect the so-called business cycle.

Table I summarizes some of the statistical properties of the overall record and the three periods. For the 120-yr record the average annual growth rate was 3.5% with a standard deviation of about 5.1%. This overall average comes from nearly comparable annual average growth rates in Periods I and III (4.5% yr^{-1} and 4.1% hr^{-1}, respectively) with a substantially lower value (1.56% yr^{-1}) during Period II. Period II was also a time of great volatility in the annual rates as shown by the large standard error.

It should be noted that it is not sufficient to forecast the average annual fossil fuel rate-of-growth to give the correct total emission during the period. A forecaster in 1860 correctly predicting a 3.5% annual average growth for the next 120 years would also have predicted the total CO_2 emitted fairly well. If, however, the growth rate during Period III had occurred before Period II, the total emission would have been about 40% greater than it actually was, even though the mean annual growth rate was unchanged.

The statement that major wars interrupt the 'steady' growth needs to be looked at. The average annual growth between 1915 and 1918 was about 2.8% and between 1939 and 1944 it was about 2.6% whereas between 1919 and 1929 it was 2.5%. Each war had one year of very large decrease (1914, 1945) but otherwise the average annual growth rate during the wars was not much different than during the subperiod without either war or the Depression.

TABLE I: Statistical summary of average growth rates of fossil fuel CO_2 production

	Period	N (yrs)	Median (% yr^{-1})	Mean (% yr^{-1})	Standard deviation (% yr^{-1})	Standard error (% yr^{-1})
I.	1861–1913	53	5.4	4.50	3.60	0.49
II.	1914–1949	36	2.5	1.56	7.62	1.27
III.	1951–1980	30	4.5	4.10	2.67	0.49
Total	1861–1980	120	4.6	3.51	5.13	0.47

If indeed the World Wars and the Depression were all that prevented the world from continuing on a set course of fossil fuel growth, where would we be now had these calamities been avoided? Had the world continued after 1913 the course of the previous 50 years, it would now be using about three times the fossil fuel it did use in 1980. (The atmospheric concentrations would probably be a little greater than 400 ppm and we would be anticipating 600 ppm shortly after the turn of the century.) The percapita world use of fossil fuel would now be about equivalent to that in Western Europe today.

It is very unlikely the world could have sustained this growth rate even without the disruptions of Period II. The extrapolation of the Period I growth rate implies that an additional 260 GTC* would have been emitted by 1980. The estimated reserves of petroleum (the amount of petroleum known to be recoverable at today's prices with today's technology) are only large enough to have contributed at most about one-third of this additional carbon. If all the additional carbon had come from petroleum, the total estimated resources (the amount believed to be ultimately discoverable) would have been exhausted. An energy 'crisis' would thus likely have occurred much sooner with a consequent lowering of the growth rate even without the political and economic upheavals of the 1914–1950 period.

These considerations suggest that a 3.5% annual growth rate is a better value to use as a base for extrapolations out to 100 years or so. Although larger rates can be sustained for several decades, there is no justification in the historical record for using a sustained 4.0 to 4.5% annual growth for over 50 years.

Acknowledgements

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* Gigatons of Carbon.