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SOLAR AND ECONOMIC RELATIONSHIPS:[1] A PRELIMINARY REPORT

SUMMARY

Jevons' analysis, 2.— Other theories of cyclical relations: Moore, 4; Huntington, 5.— The solar cycle, 7.— Correlation between solar and economic cycles, 9.—Changes in solar cycles and economic series, 10. — Variation in latitude of sunspots and index of physical production, 11.— Correlation between solar cycles and non-agricultural series, 13. — The explanation of this relation, 23.— Theories: Pigou, 26.— Hexter, 28 — Vallot, 29.— Effect of ultraviolet rays, 31. — The electrical hypothesis, 33 — The volcanic dust theory, 35.— Correlation between temperature and business activity, 38.— Correlation between monthly figures of the "preferred solar constant," business activity, and solar radiation, 42.— The last depression and the psychological theory, 45. — Monthly variations in speculation and solar activity for 1929, 46. — Sunspots in the central zone and speculation, 49.— Conclusion, 51.

This paper is an outgrowth of an attempt to establish a factual basis for the orthodox viewpoint on Jevons' hypothesis concerning business cycles and sunspots. As the investigation progressed, it was found necessary to widen its scope;

1. The investigation was made with the aid of two grants from the Committee on Research in the Social Sciences of Harvard University. We are indebted to Mr. Edgar Lawrence Smith of New York City for friendly encouragement and wise counsel. Dr. M. J. Fields of Harvard also rendered valuable assistance.

Dr Mata is responsible for the idea upon which the investigation is based, for the bulk of the research, the charts and the report to the Committee. Dr. Shaffner collaborated in outlining the original project and in the preparation of this paper, which is based on the report.

This article represents a preliminary examination of certain phases of the subject which, along with other aspects of the question, will be treated in greater detail in a forthcoming book by the present writers.

and the results, while in one way they confirm the orthodox viewpoint, indicate that the last word on the general subject has not yet been said. The present article is to be considered as a provisional report only, now published to suggest possibilities of further research and as a means of inviting criticism and suggestions. It is in no sense offered as final or conclusive.

For more than half a century orthodox economists preferred to treat the Jevonian hypothesis more as an intellectual speculation than as a scientific theory. Tho the theory has recently gained so much attention that economists have not been able to ignore it completely, it was not difficult to prove that the supposed close relation between the solar cycle and agricultural fluctuations did not in fact exist. But when the analysis was extended to economic phenomena other than agricultural fluctuations, the evidence disclosed a resemblance between the solar cycle and business activity so close as to command serious consideration. Indeed, this evidence was so striking that we thought it necessary to conduct further investigations to prove the resemblance accidental. In this we were unsuccessful, and therefore we were obliged to seek in the literature of solar-terrestrial relations all the available material which could be used to sustain the hypothesis of some direct connection between them. This material, together with all the additional evidence that we have been able to dig up in the last two years and some possible interpretations of it, is submitted herewith.

As is well known by all students of the subject, Jevons' hypothesis was that the variation in the number of sunspots produced corresponding variations in crops and that through this channel business cycles were brought about. Working on the assumption that the sunspot cycle had an established length of 11.11 years, he tried to find a periodicity of similar length in agricultural prices. His failure to do so is now well known and was recognized at the time even by himself.

There are several reasons for Jevons' lack of success. First of all, the statistical tools necessary to treat time series in such a way as to establish clearly the length and shape of the fluctuations and their correlation with other time series had not then been developed. Furthermore, altho the solar cycle has been detected clearly in several terrestrial phenomena, especially magnetism, in meteorological data, it can be seen only by averaging the local variations, which for a given locality are very much more important than the solar cycle. Taking the world as a whole, the solar cycle appears clearly,[2] but it would be difficult to detect it in the British Isles, where the data which formed the basis of Jevons' calculations were collected.

In his investigations, Jevons went as far back as 1701, twenty years before the South Sea Bubble, and after a detailed search in old records he found evidence of unbroken periodicity of the more or less decennial crises. Counting the crises between the "unquestionable collapses" of 1721 and 1867, he obtained an average of 10.43 years between them.[3] Using other starting points, he found similar periods, and remarked on the striking coincidence between that figure and the average of 10.45 years which he sought to assign to the sunspot cycle. But he could "see no reason why the human mind, in its own spontaneous action, should select a period of just 10.44 years to vary in. . . ." Some outside phenomenon related to the solar cycle, he continued, was timing the industrial waves so as to make them fall in line with the solar period.

Jevons, tho unsuccessful, was truly ahead of his time. He regretted that the astrophysicists were depending on a value of the solar "constant" made by Pouillet in 1837, instead of making daily measurements to find out if the "constant" varied.[4] The astrophysicists did not suspect such variability until the measurements of Langley in 1903; and only after

2. Tho mixed with the effect of other worldwide terrestrial phenomena.

3. Jevons, W. S., Investigations in Currency and Finance, p. 215 (the paper on "The Periodicity of Commercial Crises and its Physical Explanation," read at the meeting of the British Association on August 19, 1878).

4. Op. cit., p. 234. Altho Jevons was the only economist to expound a well-rounded theory of the connection between solar and business fluctuations, his studies were in part anticipated by Sir William Herschel

1919 were daily records kept by the Smithsonian Institution — records which allowed Dr. C. G. Abbot in later years to prove the true variability of the so-called solar "constant" of radiation.[5]

The solar hypothesis of business cycles thus remains today more or less in the same status that it was in 1882, at the time of Jevons' death. But other theories are commonly cited in textbooks in connection with the Jevonian hypothesis. Of these we shall mention only those that offer a cosmic explanation, the investigations that refer simply to the connection between crops and business cycles being left for discussion later.

The first of these is Professor H. L. Moore's theory, expounded in 1914 and elaborated in his book published in 1923.[6] It is founded on his discovery of an 8-year cycle in the annual rainfall in the United States from 1881 to 1921, correlated with identical cycles discovered previously in a much longer record of rainfall in the Ohio Valley, and corroborated by a somewhat similar cycle in English wholesale prices. Professor Moore's theory is that "a known natural cause originates an agricultural cycle which in turn generates other economic cycles," the natural cause being the lapse of 8 years between the return to "the maximum approach to a straight line" in the periodic conjunctions of the earth and Venus with the sun.[7] This, he maintains, is the origin of the agricultural 8-year cycle generated with the business cycle.

Without entering into the debatable merits of the harmonic analysis employed by Professor Moore, we merely note that one of the most important links in Moore's reasoning is his transition from agricultural prices to general business series. Concerning this, we may quote the conclusions of Dr. Warren

in 1801, and influenced by Heinrich Schwabe's discovery in 1847 that sunspots moved in cycles.

5. "Annals of the Astrophysical Observatory of the Smithsonian Institution," Washington, 1932, vol. v, p. 2. The present investigation owes much, at various points, to the pioneering work of Dr. Abbot

6. Henry L. Moore. Economic Cycles, Their Law and Cause, New York, 1914; and Generating Economic Cycles, New York, 1923.

7. Ibid., p. 97.

M. Persons, the result of a careful statistical study. "We have found, then, that the production and prices of agricultural commodities do not exhibit cyclical or wave-like movements such as appear in the changes of general business conditions and of the general commodity price level, but rather show oscillatory year-to-year fluctuations." Furthermore, there are many logical reasons for denying the relation, at least in the large industrial countries.

The assumption is that the solar influence is felt in the variation of the yields. But Dr. W. M. Persons has demonstrated that while there is extremely high correlation (+.92) between yields and physical production of crops in the United States, the correlation between physical production and total values is almost nil (−.04).[8] Hence the argument that the variation of yields affects the purchasing power of the farmer is not true, for the simple reason that the law of supply and demand takes care of that. Perhaps in agricultural countries in which prices are regulated by the world market (for example, Australia or Argentina) it would be possible to maintain that a high yield in the year's crops can bring prosperity to the whole country. The American farmer knows well, however, that bumper crops sometimes bring prices so low that all the earning margin is gone, and he cannot even pay the expenses of harvesting the grain.[9]

Much more interesting from our point of view in the research on Jevons' theory is Professor Ellsworth Huntington's theory, because of its new approach in the search for the "missing link" between solar variation and business fluctuations. He thinks that the relation is an indirect one,

8. W. M. Persons, Forecasting Business Cycles, New York, 1931, p. 193.

9. Jevons' son has lately published an article restating the whole theory, in the Journal of the Royal Statistical Society, vol. xcvi, Part iv, 1933, p. 545. In this he quotes an article published in 1917 in the Indian Journal of Economics, in which a list of crises since 1670 is recorded with a frequency distribution which looks similar to the "sunspot cycle"; but the same arguments about the importance of crops in economic life are repeated, without new proofs of the existence of the solar cycle in crop data. Therefore the theory remains in the same situation as before. This new article of Jevons' son, however, admits and stresses the necessity of more research in the field.

operating through an influence of solar radiation on health and of health on business. "Business cycles," he writes, "appear to depend largely on the mental attitude of the community; and the mental attitude depends on health."[1]

That business cycles depend on mental attitude can be accepted; but Huntington's proof that the mental attitude depends upon health is not convincing, because he based his statistical correlation on various lags. He found the following ones:[2]

1 year between health and mental power
1 year between health and school attendance
3 years between health and New York bank clearings
4 years between health and general business
4 years between health and national bank deposits
5 years between health and immigration

As Sorokin has said of Huntington's theory, "The use of elastic 'lags,' which shorten and lengthen according to the requirements of the problem, can make correlations where none exist."[3] Since Huntington uses death rates *inverted* as a health index (a procedure in itself open to discussion),[4] it is possible through adequate lags to prove statistically the reverse, i.e. that bank deposits, immigration and business *precede* death rates.

Summing up, we may state that in the economic field the present status of the solar hypothesis of the business cycle is as follows:

First, the fact of a correlation between the solar cycle series and a business cycle series has not yet been established through statistical methods.

Second, the logical reason for a connection has not been found. There is still a "missing link," as Jevons said. The explanations through weather and crops have not been proved sound, and the same can be said of the explanations

1. E. Huntington, World-Power and Evolution, New Haven, 1920, p. 29.
2. Op. cit., p. 36.
3. P. Sorokin, Contemporary Sociological Theories, New York, 1928, p. 127.
4. Sorokin, ibid., p. 140

through the effect of meteorological phenomena on human health.

During the period of more than fifty years since the original investigation of Jevons, astronomical knowledge of solar radiation has advanced enormously, particularly in the last two decades.[5] The use of the spectroscope enabled Hale, in 1908, to make the important discovery that sunspots form magnetic fields, and the fact that they shoot electrons to the earth prepared the way for a more logical explanation of the relation between solar and terrestrial phenomena.

In 1919 the Smithsonian Institution began to keep daily records of the amount of solar energy that reaches the earth, at stations which were established in appropriate locations throughout the world; and since 1924 the Mount Wilson Observatory has kept records of the variations of the ultra-violet light received from the sun. Both phenomena have been found to move in cycles, and this confirms the proposition that there is an actual variability in the sun's radiation. The solar cycle has been ascertained in many other manifestations of solar activity — the shape of the corona, the area of the "faculae" or "bright" spots, the prominences in the sun's limb, and other phenomena.

Recently it has been noticed that a close relationship appears to exist between this solar cycle and various terrestrial phenomena. Among these may be mentioned the established connection between the solar cycle and variations in the earth's magnetic field[6] — the timing of magnetic storms, the state of radio reception,[7] the thickness of the skin of fur-bearing animals, the thickness of tree rings.[8] Further

5. All the facts about solar astrophysics quoted in this paper, except those specifically acknowledged, have been taken from the authoritative source, Handbuch der Astrophysik, J. Springer, Berlin, 1929, vol. iv.

6. A study of this subject covering the period 1873-1902 is to be found in Monthly Notices of the Royal Astronomical Society, vol. 63, p. 462.

7. Stetson, H. T., "Solar Activity and Radio Reception," Monthly Weather Review, January, 1933, p. 1.

8. The data on this, discovered by Douglass, extend back for over

relationships between the solar cycle and terrestrial phenomena which have been claimed to exist but which have not yet been satisfactorily proved, could easily be enumerated. The work of the Permanent Committee of the International Research Council appointed to further the study of solar-terrestrial relationships will in the near future probably throw additional light upon this whole problem.

With this considerable amount of new data available, it seems worth while to attempt a fresh statistical investigation of Jevons' hypothesis. We have not only better and more complete astronomical data, but also more accurate economic measurements, and particularly the advantage of the statistical technique which has developed so greatly since Jevons' time.

In the first place, we find that it is not possible to rely on an exact figure for the length of the sunspot cycle, as Jevons did. There is no exact "period." According to the Wolfer tables the length has varied in the last three centuries (since the discovery of the existence of the sunspots in 1608, when the telescope was first used by Galileo) between 8.2 and 15 years, as counted from minimum to minimum. The arithmetical average from 1610 to 1913 is 11.215.[9] According to a statistical investigation of the problem by G. U. Yule,[1] there seems to be no secondary period, and the frequency distribution is similar to that of a pendulum disturbed by random impulses. Using the crude data available for the period 1749–1924, he obtained, by the harmonic formula, 10.08 years and, by the regression equation, 10.60 years. Employing graduated data and the same methods, he obtained the values of 11.03 and 11.164 years, respectively.

C. G. Abbot believes that the true period is probably 22.6

1,000 years. See the compilation Quaternary Climates, Carnegie Institution, Washington, 1925.

9 Handbuch . . . , loc. cit., p. 99. Solar cycles are more clearly defined by taking data of minima activity than they are by resort to maxima

1. "On a method of investigating periodicities in disturbed series with special reference to Wolfer's sunspot numbers," by G. Udny Yule, Phil. Trans. Roy. Soc., 1927, vol. 226, p. 267.

years, between two minima of identical electrical nature (the intervening minima not being clearly fixed). He shows that for the last century — the period for which we have reliable data — the deviations from the 22.6-year period have been less than 0.7 year.[2] On the other hand, H. W. Clough is of the opinion that the variations in the amplitude of the period are consistent and show several cycles of 37, 83 and 300 years. He offers evidence which dates back to 300 A.D., based on records of the aurora borealis, and finds a "normal" value for the period of 11.067 years.[3]

From all this evidence it is clear that no harmonic analysis or other method based on an assumed fixed period should be used in this investigation. Nor is the method used by Jevons of "counting" the panics and obtaining an average length adequate, because there is no exact average for the solar cycle, and it is difficult to detect all the definite depressions, as well as the actual low points of the economic curves, which should be counted. Furthermore, even if an average is found exactly similar to the solar average, the relationship would be nonexistent if the "tops" and "bottoms" of the individual business cycles showed a disagreement with the highly variable ones of the solar cycle.

Probably the best method is to correlate the time series of sunspots or other solar phenomena and the time series of economic activity over the same period.

Following this method, we have chosen the solar data of the Greenwich and Kodaikanal Observatories, published by the Royal Astronomical Society. They are the most reliable sources because they consist of daily measurements taken from photographs of the area of the sunspots, measured in millionths of the solar visible hemisphere and given in mean daily averages. It is true that these data go back only to 1874, whereas the "sunspot numbers" of Wolfer are available since 1749; but Wolfer's later ones are more or less arbitrarily

2. Reports of the Conference on Cycles, Carnegie Institute, Washington, 1929, p. 47.

3. "The 11-year sunspot period, secular periods of solar activity, and synchronous variations in terrestrial phenomena," by H. W. Clough, Monthly Weather Review, Washington, April, 1933, p. 99.

measured by a formula which combined groups with the number of spots, and the data for the years previous to 1833 are not the result of systematic observations.[4] Other reasons for using the Greenwich observations are that they publish similar data for the area of the faculae (or "bright" spots in the solar surface) which, varying for the same cycle, will be useful for us as another index to check; and that the economic data of American business previous to 1874 are not as complete as the data since that time. And a final reason is that henceforth we shall deal entirely with facts subsequent to the Jevons investigation.

For the economic data we shall use first the index compiled by Dr. W. M. Persons, not only because it covers exactly the same period but because it gives partial indices — of crops, minerals and manufactures — which are especially useful for our purposes. It is to be added that as regards the annual data with which we are dealing there is little difference between the various authoritative yearly indices of American business activity; several of these have been tried graphically, with substantially the same results.

Dr. W. M. Persons has demonstrated that the index of the physical production of crops corresponds closely to the changes of yield per acre (the correlation of the changes from year to year reaches the high figure of +.92).[5] Therefore this is a good index to use in the investigation to find out whether the solar cycle affects the total amount of production of crops in the United States. Since the purpose of the investigation was to test the Jevonian assumption of the existence of an 11-year cycle in both phenomena, and since this cycle can be hidden behind year-to-year fluctuations, and since Persons has noted that sharp year-to-year fluctuations are a clear feature of the index of crops,[6] the necessity of smoothing the data is evident. A 3-, 4-, or 5-year moving average would have been a simple method to employ, but this method

4. See W. J. S. Lockyer, "The Solar Activity 1833–1900," in Monthly Notices Royal Astronomical Society, vol. 61, p. 43.

5. Warren M. Persons, Forecasting Business Cycles, New York, 1931, p. 192.

6. Op. cit., p. 193.

involves the prejudice of assuming the existence of a 3-, 4-, or 5-year cycle, and will not correctly reveal the turning points. This defect has been analyzed by Dr .F. R. Macaulay in his pioneering book.[7] Following Macaulay's suggestion, we have used a weighted moving average of seven terms whose "graduation weight diagram" shows a smooth curve roughly comparable with the ones of Macaulay.[8] The formula is

$$d = \frac{a+3b+5c+6d+5e+3f+g}{24}.^{9}$$

The comparison of the two curves appears in Chart I, in which the actual data and the smoothed values are both pictured. The absence of correlation between the cycles of the solar curve and the smoothed line of the variation of crops appears so clearly that it has not been considered necessary to calculate the coefficient of correlation.

The results of the graduation of the crop figures are interesting, because they not only show the nonexistence of a definite cycle corresponding to the solar cycle but also evidence of fluctuations which have been detected by other investigators. Something like a pronounced wave is apparent. The graduated line crosses the normal line downward in 1885–86 and in 1919–20, i.e. 34 years apart. This long cycle of 33 or 35 years is quite obvious in the chart, altho the length cannot be determined with exactness, owing to the shortness of the period considered. This is evidently the so-called Brückner cycle[1] that has been found in so many

7. F. R. Macaulay, The Smoothing of Time Series, New York, 1931.

8. Ibid., pp. 77–79. We cannot use more terms without interfering with the 11-year periodicity.

9. From a practical point of view this method has the advantage that it can be used by taking a 4-year moving average of a 3-year moving average of a 2-year moving average, and this is very important in an investigation like the present one in which so many curves must be tested.

1. E. Brückner, Professor of Geography at the University of Bern, discovered it in 1890 when studying the records of the level of lakes without outlets. The oscillations were found in all the lakes considered and were alike (the lakes were distributed in the five continents). The average for them, from 1020 to 1890, was 34.8 years (but the individual

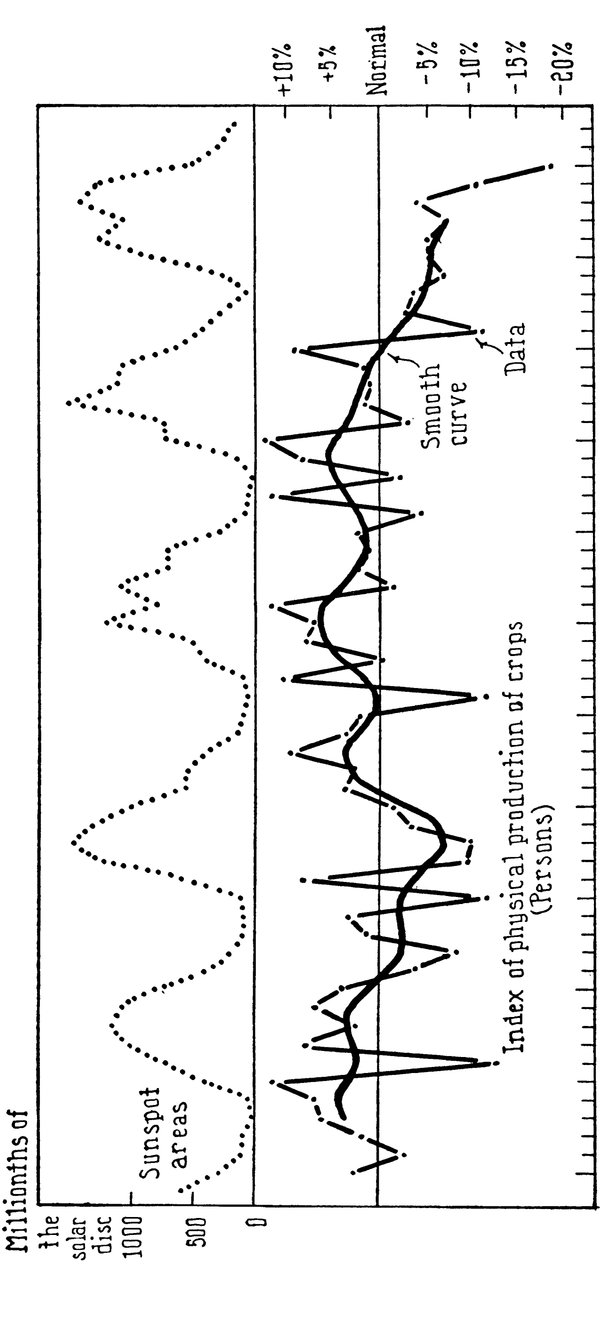


CHART I

Data for sunspot areas are from the Royal Astronomical Society.
Data for physical production of crops from W. M. Persons, "Forecasting Business Cycles," pp. 182–183.

agricultural series and in other terrestrial phenomena. The last maximum year given by Brückner as "wet and cold or wet or cold" was 1880, and this figure agrees approximately with our graduated curve, since the top of it was about that date.

This result coincides with the findings of Moore, referred to above. He notes that a $33\frac{1}{3}$-year cycle is predominant, and we know that the length of the Brückner cycle is quite variable.[2]

In addition to this wave, our curve shows five cycles of 6, 6, 8, 8 and 8 years, starting in 1881 and ending in 1917, making an average of 7.2 years. At the end of the curve, however, there is no definite cycle. Probably this kind of fluctuation is the same as that referred to by Moore as an 8-year cycle, and by Clough as a 7-year cycle.[3]

Persons' index of the physical production of manufactures, after the same smoothing process used previously for the crop index, showed a surprising result. Five cycles appeared clearly between the actual bottoms of 1876 and 1932, making

cycles varied from 20 to 50 years). See Sir Richard Gregory's "Weather Recurrences and Weather Cycles," in Monthly Weather Review, December, 1930, p. 485.

2. Several attempts have been made to correlate the Brückner cycle with solar activity. See "Notes on Lake Levels," by J. W. Shuman, in Monthly Weather Review, March, 1931, p. 97; and "The Solar Activity 1833–1900," by W. J. Lockyer, in Monthly Notices of the Royal Astronomical Society, vol. 61, p. 43. We made an investigation about the possibility of a *direct* correlation of the secular trend of the sunspot series (as shown by an 11-year moving average of the sunspot numbers, 1749–1933) with the "long waves" of the economic series. The result was negative. The solar secular cycle shows something like two waves with bottoms around 1810 and 1900. A graphic comparison with wholesale prices in England showed some agreement until 1870, but no correlation afterwards. Similar results were obtained with the curve of the price of British consols for the whole period. The main solar secular cycle seems to have a length of about 80 years, and therefore cannot be correlated with the "Kondratieff" cycle of about 50 years. It is interesting to note that this 50-year cycle in economics was cited by Jevons as having been discovered by a Dr. Clarke in 1847. See Investigations . . . , p. 223.

3. H. W. Clough, "An approximate seven-year period in terrestrial weather, with solar correlation," in Monthly Weather Review, October, 1920.

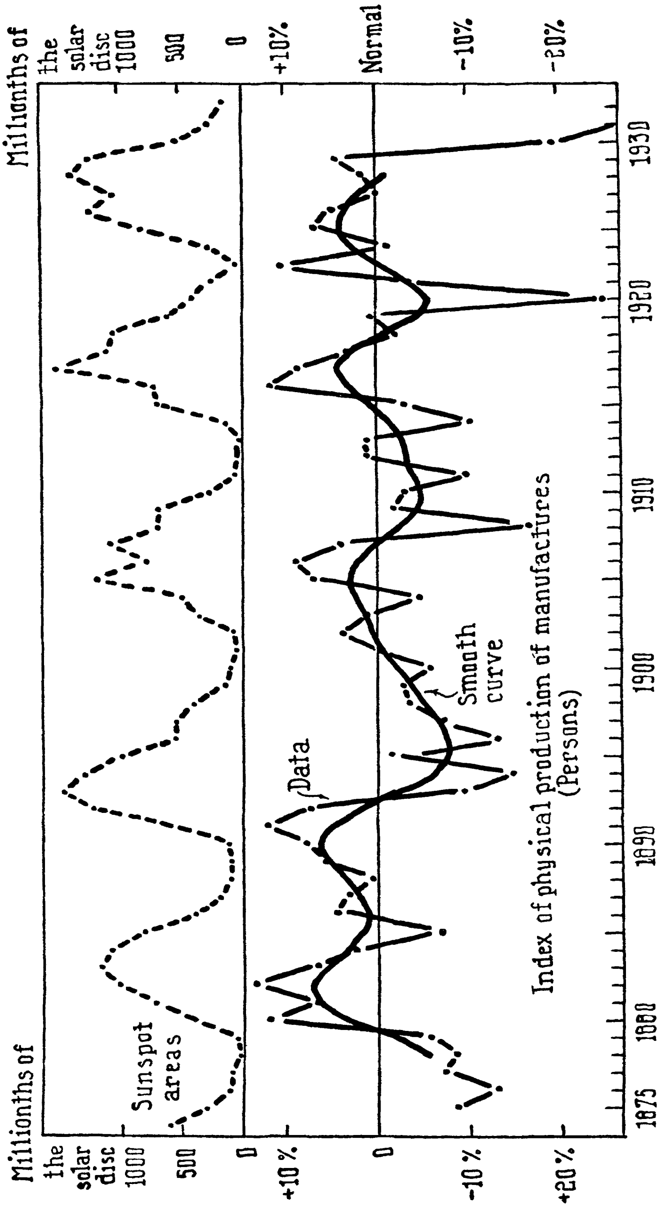

Millionths of the solar disc
1000
500
0
+10 %
0
-10 %
+20 %
Millionths of the solar disc
1000
500
0
+10%
Normal
-10%
-20%
Sunspot areas
Data
Smooth curve
Index of physical production of manufactures (Persons)
1875
1880
1890
1900
1910
1920
1930

CHART II

an average of 11.20 years. The average of the last five sunspot cycles (not counting the present minimum, which is not yet clearly established) is 11.16 years. But a graphic correlation of both curves (see Chart II) showed that the correlation should be inverse, i.e. increase of sunspots correlating with decrease in business. The main explanation is in the known fact that the solar cycle takes longer to fall than to rise; and the 11-year business cycles of our smoothed curve showed clearly a rise much slower and longer than the fall in the depression periods. A graphic comparison with the solar curve inverted showed, nevertheless, that to get a high correlation through agreement of tops and bottoms a lag of three or more years was necessary, i.e. the solar curve three years ahead of the business curve. The necessity of introducing such a long lag to produce the best correlation seemed to us more an indication of the correlation's being accidental than a proof of the true relationship between both curves. Notwithstanding this, the fact that the varying length of the five individual solar cycles showed individual resemblances to those of the respective business cycles was a strong argument against closing the investigation at this stage. The other solar curve of the Greenwich records was used, with a similar result, i.e. the solar faculae, when inverted, showed the same relationship and the same lag.

The curves of solar variation so far considered are those of the variations as seen in the sun. The possibility of a different timing of the variation of the solar cycle as received on the earth was sought. The variations of the solar radiation as measured by the Observatories of the Smithsonian Institution are available since 1919, and altho they show clearly the 11-year cycle the timing is not the same as that of the sunspots. According to Dr. Abbot, under whose supervision these observations were made, "as indicated by all our observations, the solar radiation rises to a maximum with *medium* sunspot numbers and declines thereafter as sunspots increase."[4] This is exactly the same behavior as that observed

4. Report of the Conferences on Cycles, Washington, 1929, p. 75. This difference in timing between the sunspot curve and other solar

in the correlation between the sunspot curve and the business curve. A long record of solar-radiation observations is not available, and therefore a test for the whole period is not possible. But since the kind of relation described by Dr. Abbot as existing between the sunspot curve and the solar radiation is more or less a description of the behavior of a first-difference curve in relation to the curve of the original data, we constructed a curve of the yearly changes of the area of the solar spots. After this curve was smoothed in a way similar to that of the economic curve, and both were plotted together without the aid of a lag, and the zero lines made to coincide without changes in the scales, the results were striking. The relationship, as shown on Chart III, is much higher than was expected, because the shape of all five individual cycles is surprisingly close. If this is an accidental relation, it is probably a most unusual example of it.

When the curve of the first-differences of the solar-faculae series was constructed, it showed the same results, and the correlation with business remained as before, as can be seen also in Chart III.[5]

The same investigation was made regarding the index of physical production of minerals, which together with that of crops and manufactures forms Dr. W. M. Persons' index of physical production in the United States. The three indexes, compared with the solar cycle, may be seen in Chart IV.[6] The chart shows clearly the surprising fact that there is no correlation between the solar cycle and the fluctuation of crops, but that there is a close correlation between the solar cycle and the other indexes of physical production. The coefficient

terrestrial curves had been shown graphically by F. H. Bigelow in A Treatise on the Sun's Radiation and Other Solar Phenomena, New York, 1923, 234.

5. The two top curves represent the first differences, and the first differences smoothed, of the sunspot areas depicted in Charts I and II.

The two middle curves represent the first differences and the first differences smoothed, of solar faculae.

The two bottom curves show the relationship between the sunspot curve (smoothed) and Persons' index of manufactures (smoothed).

6. Persons' unadjusted data are given in his Forecasting Business Cycles, pp. 182–183.

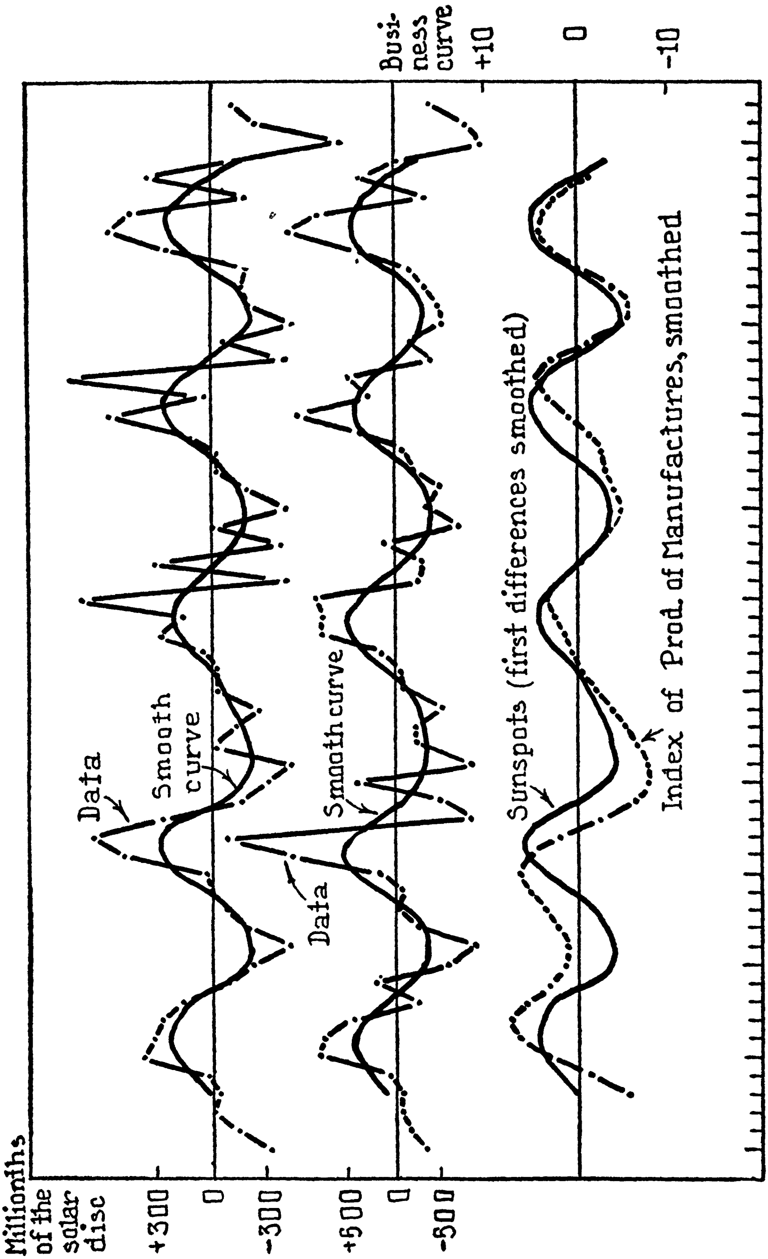

Millionths of the solar disc
+300
0
-300
+600
0
-600
Business curve
+10
0
-10
Data
Smooth curve
Data
Smooth curve
Sunspots (first differences smoothed)
Index of Prod. of Manufactures, smoothed
1875
1880
1890
1900
1910
1920
1930

CHART III

of correlation between the smoothed curves of yearly changes in sunspots and production of manufactures proved to be $+.690 \pm .049$. Since $+1.00$ would indicate absolute agreement the correlation is a high one. It is to be noted also that the probable error is very small.

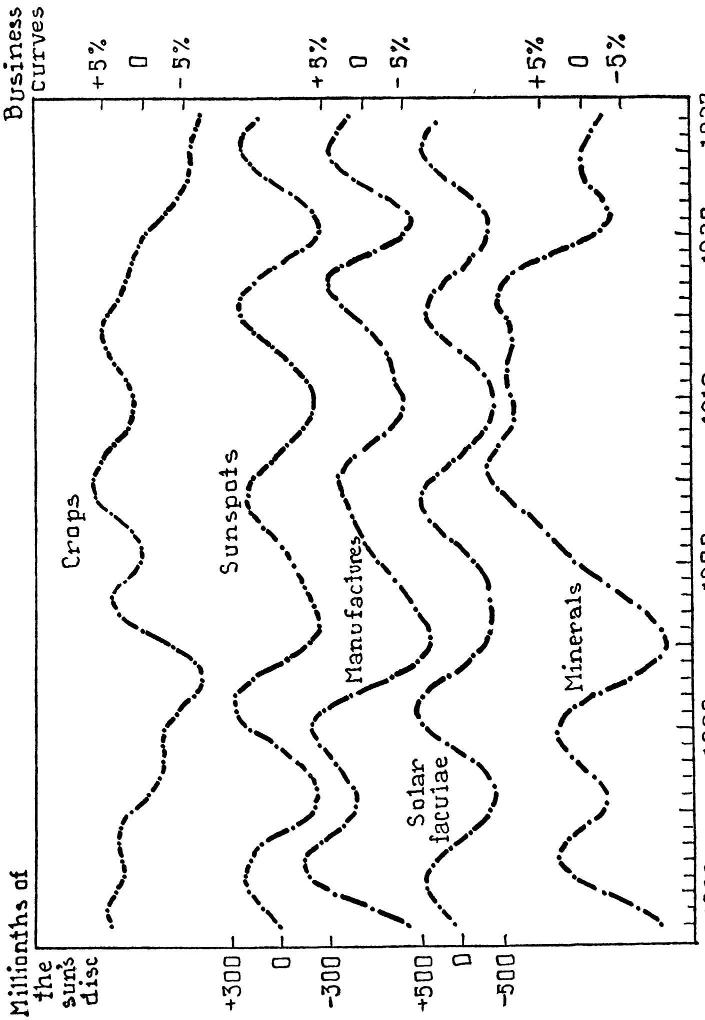


CHART IV

As the correlation is so surprising, another kind of comparison was devised as a check. With Persons' data we have constructed an index that includes total physical production, excepting crops (using Persons' weights: Manufactures, 56; Minerals, 8). Starting on the assumption of the existence of something like a 3½- to 4-year cycle in business series, which so many investigators have found,[7] it is clear that a 4-year moving average will eliminate that kind of fluctuation, and all the other longer cycles ought to remain. When that was done and the resulting curve was plotted with the solar curve, the same clear correlation between the increase and decrease in sunspots and the business cycle was revealed.[8] This may be seen in Chart V.

As a further step without regard to smoothing, we took the actual figures of this total index of physical production (excluding crops)[9] and compared it with the yearly changes of the areas of solar faculae, which are a better solar index for uses without smoothing than are sunspots, because the faculae areas are twice as large as the spots. The results are shown in Chart VI. Notwithstanding thefact that for logical reasons a first-difference curve is usually subject to sharp fluctuations from year to year which simple smoothing can average out, the crude data of the graph show that the relation is plainly visible without any mathematical manipulation. It is interesting to note that the solar curve reaches in the last decline, 1929–30, the lowest point of the entire 56-year period.

We have not found in the astrophysical literature references to this cycle of the yearly changes of solar phenomena, but Dr. Bauer of the Carnegie Institution is reported to have said that "as a combined result of his investigations to date, he found that, in general, the most successful measure of solar activity, especially when comparisons between solar and ter-

7. See W. C. Mitchell, Business Cycles, New York, 1927, pp. 344 and 385.

8. The coefficient of correlation remained high· + 644 ± .055.

9. The Persons "Total" indexes could not be used here because, as we have seen, they include crop fluctuations which are quite different from those of non-agricultural production.

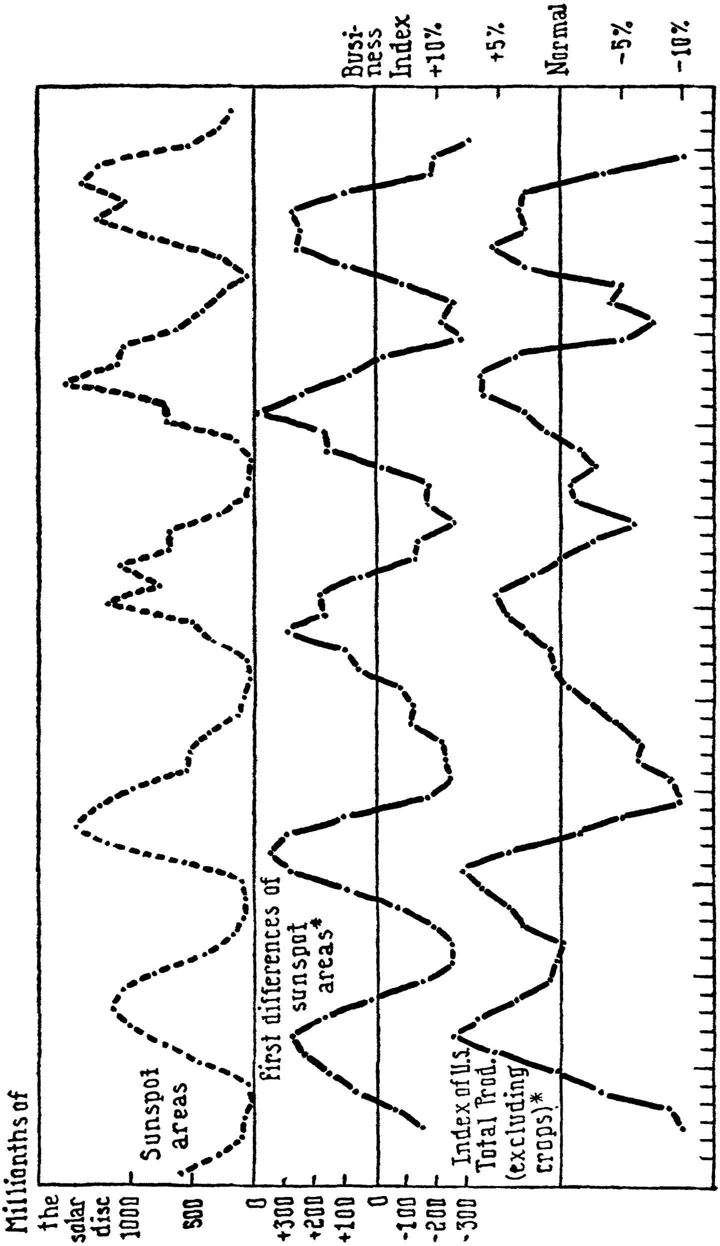

Millionths of the solar disc
1000
500
0
Sunspot areas
First differences of sunspot areas*
+300
+200
+100
0
-100
-200
-300
Index of U.S. Total Prod. (excluding crops)*
Business Index
+10%
+5%
Normal
-5%
-10%
1875
1880
1890
1900
1910
1920
1930

CHART V

restrial data are attempted for smaller intervals than a year— a month, let us say — is a quantity indicative of the amount of *variability* of sunspottedness during a given period."[1] It is curious that our graphs show the best correlation with curves of sunspot *variability*, tho yearly instead of monthly.

Another attempt was made, with an entirely different method, to test the existence of this curious direct correlation of the solar cycle with the production of manufactures — curious because it appears regardless of the fact that there is no clear connection either of the solar cycle with crops or of the crop cycle with the business cycle.

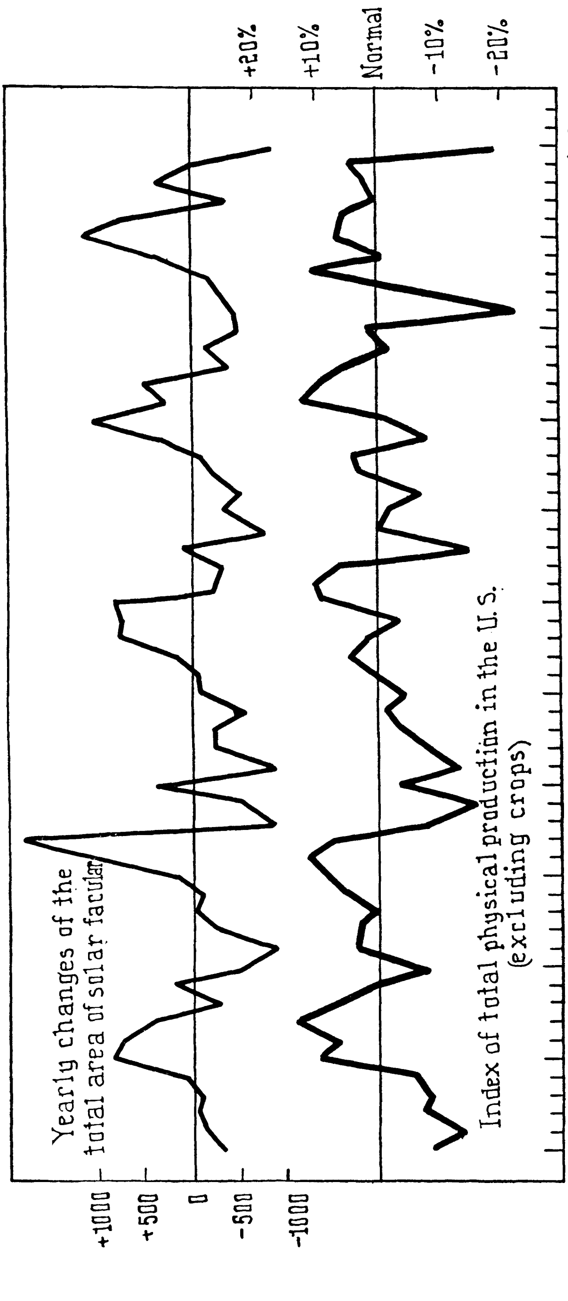
The clearest sign of the existence of a cycle in the sun is the so-called "Spoerer Law" of the variation of the latitude of the sunspots. Instead of a curve being formed by a variability that increases and decreases, like the total amount of spots, the latitude measurements are broken with the beginning of a new cycle every 11 years. In other words, at the beginning of the cycle the spots are distributed in two belts, between 20° and 40° latitude at both sides of the equator. Then during the whole solar period they appear each year nearer to the equator, and at the end of the period they are centered around it at about 6° on either side. (The actual equator seldom has spots). Then the new cycle is suddenly announced by the appearance of new spots (with reversed electrical polarity) at about 40°; and, as the spots of the old cycle near the equator disappear, the two belts of the new cycle are being formed in the higher latitudes.[2]

With this phenomenon in mind, a frequency distribution was made of the yearly figures of the index of physical production of manufactures,[3] according to the mean latitude of

1. Reports of the Conferences on Cycles, Washington, 1929, p. 17 (italics are Dr. Bauer's).

2. Similar phenomena occur with the faculae, altho the latitudes are different. This law is perfectly portrayed in the so-called "butterfly diagram," in which sunspots are plotted in relation to time and latitude. See Handbuch . . . , quoted above, vol. 4, p. 98.

3. We have preferred to use this index and not the one of total production, in order to exclude the crop phenomena, which, as we have seen, fluctuate without direct relation to the solar cycle.



Yearly changes of the total area of solar faculæ
Index of total physical production in the U. S. (excluding crops)
+20%
+10%
Normal
-10%
-20%
+1000
+500
0
-500
-1000
1875
1880
1890
1900
1910
1920
1930

CHART VI

the sunspots during the year (given by the Greenwich records). See Chart VII. The results — arranged in three columns to cover prosperity (index over 105), normal times (index 95 to 105) and depression (index below 95) — are as follows:

	Number of Years (for Period 1875–1932) in which the Index of Manufactures was:			
Latitude of sunspots	High (Over 105) (A)	Normal (95–105) (B)	Low (Below 95) (C)	Percentage of (A) in total
Above 21°	1	2	2	20
19° to 20.99°	3	1		75
17° to 18.99°	4	2		66
15° to 16.99°	2	2		50
13° to 14.99°	4	2	3	44
11° to 12.99°	1	3	2	17
9° to 10.99°		9	4	0
7° to 8.99°		4	6	0
Below 7°			1	0

As can be seen from the last column, the percentages show, with the exception of the first one, a consistent law. It may be noted that the years which have an average latitude of sunspots of more than 21° are the rare years in which spots in higher latitudes of a new cycle are averaged with the lower latitudes of the dying old cycle; hence the mean value is a somewhat artificial figure.

In a more condensed form the same results are tabulated in the following table, according to the years in which the latitudes of the spots were above or below the mean latitude for the whole period, which proved to be 12.5°. See Chart VII*b*.

Distribution of the Yearly Indices of Production of Manufactures, 1874–1932

Mean latitude of sunspots	Number of years	Years with the index above normal	Years with the index below normal
Above 12.5°	29	20	9
Below 12.5°	29	9	20

There seems, therefore, to be some relation between the existence of sunspots (or rather of disturbed focus of solar activity, as the faculae and other phenomena follow the

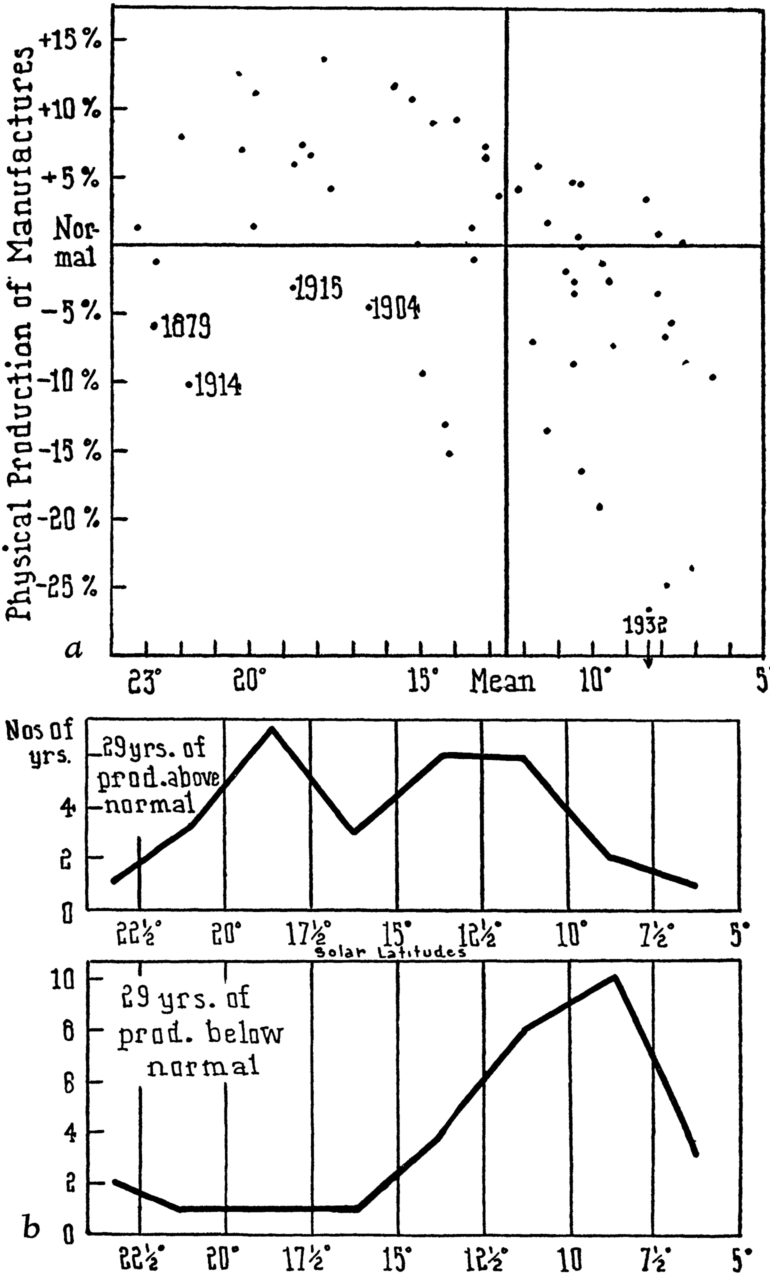

Physical Production of Manufactures
+15 %
+10 %
+5 %
Normal
-5 %
-10 %
-15 %
-20 %
-25 %
1879
1914
1915
1904
1932
a
23°
20°
15°
Mean
10°
5°
Nos of yrs.
29 yrs. of prod. above normal
4
2
0
22½°
20°
17½°
15°
12½°
10°
7½°
5°
Solar Latitudes
10
8
6
4
2
0
29 yrs. of prod. below normal
b
22½°
20°
17½°
15°
12½°
10
7½°
5°

CHART VII

Spöerer Law) near the equator and times of depression. It is generally accepted that the electrical corpuscles shot away by the solar vortex formed by the spots have a tendency to follow radial straight lines.[4] In the extreme case of following the radial straight line only, we find that only the spots in the zone below 7° 15′ around the solar equator could affect the earth, because those are the limits of the inclination of the earth's orbit in relation to the solar equatorial plane. This hypothetical case is cited here merely to stress the fact that the spots in lower latitudes ought to affect the earth more strongly than the others;[5] and because the preceding table shows that the appearance of spots in lower latitudes is somewhat associated with depressions, and their absence with prosperity in business.

Following this idea as a working hypothesis, we made a tabulation of the area of the sunspots as given daily in the Greenwich Heliographic Results, by degrees of latitude for the period 1902–31.[6] This enabled us to have a complete record (preceding tabulations were available only to 1902)[7] for the purpose of statistically delimiting a central zone whose curve of spottedness showed a direct correlation with the business curves without the aid of lags, which was necessary when the total of all the zones was taken. The result showed that such a curve was possible, and that the lag was reduced to one year or perhaps less, but that for that the data ought to

4. S. Chapman, an authority on solar-terrestrial relationships, thinks that "probably 90 per cent of the atoms will finally have velocities inclined at less than 10° of the radius." In Monthly Notices of the Royal Astronomical Society, March, 1932, p. 415.

5. The International Astronomical Union began to publish in 1928 daily data of the sunspots in the central zone "for the research of the relationships between sun phenomena and certain terrestrial phenomena." For character figures of solar phenomena, see Bulletin, Zurich, March, 1928.

6. With the assistance of the facilities of the Harvard Astronomical Laboratory. This investigation represents the continuous labor of one man over a period of three months.

7. "Mean daily areas of sunspots for each degree of solar latitude for each year from 1874 to 1902 as measured by the Royal Obs. Greenwich." Monthly Notices of the Royal Astronomical Society, vol. 63, p. 452.

be reduced to the absolute minimum limits of $+7°15'$ to $-7°15'$; and even then the correlation was much smaller than that obtained with the curve of the yearly changes, mentioned in previous paragraphs. Given different statistical weights for the spots according to their distance from the earth's plane, it would be possible to obtain a closer fit, but this suggestion was not followed because the weights would be somewhat arbitrary, and therefore the results would add very little to the evidence in hand.

Summing up, we can say that *from a statistical point of view* there appears to be a clear correlation between the major cycles of non-agricultural business activity in the United States and the solar cycle of 11+ years; but so far we have been unable to determine whether the best correlation is with the curve of the total amount of the solar disturbances with a lag of several years, or with the cycle formed by the yearly increase or decrease in disturbances in the solar surface (spots, faculae, etc.) or with the existence or absence of spots pointing directly to the earth in the solar central zone, or through some other feature of the solar cycle. *From a logical point of view* all the evidence accumulated seems to show that it is hardly possible to believe that the relations revealed are wholly accidental. Therefore we are obliged to seek reasons for the existence of such relations. Some possible hypotheses are outlined below.

Altho ever since the days of John Mills the psychological explanation of business fluctuations has been outstanding among the many competing theories, it is perhaps at the present time as much in vogue as ever before, probably more because of the expositional abilities of its best known exponent than from any inherent merits which have so far been found in the theory itself. Recent events have contributed to enhance its popularity. The last depression has converted many people to the school of thought which maintains that the business cycle is mainly a psychological phenomenon, that sudden changes in the psychological status of the community accompany the change from prosperity to depression, and vice versa. Professor Pigou, now the standardbearer of this theory, has maintained that because of the psychological interdependence of business men, an error of optimism in forecasting the future state of business gradually spreads and becomes general throughout the business community. When the error is discovered, it generates a reaction in the form of an error of pessimism, which also rapidly spreads and leads to the opposite extreme. Reversal of the process explains, according to Pigou, the return to prosperity in the cycle.[8]

In the last few years, however, it has been clear that at times when there is an abundance of technical features favoring the return of prosperity — easy money, the wearing out of goods and equipment, government agencies to aid recovery — yet revival is impeded by the failure of the public's psychology to react to such favorable external stimuli. This is a factor that cannot be explained by Pigou's theory. Why do the psychological factors fail to begin operating when all the necessary background for their inception is laid out? Why does the *timing* of these waves of optimism and pessimism seem independent of actual business conditions? Why does recovery, when all seems in readiness, have to wait for some outside impetus? It is fairly easy in economic theory to explain *how* all the features of the business revival engender one another, once the wave has started, but much more difficult to explain *why* it sometimes starts unexpectedly at a given moment and fails to start at times when it logically ought to.

To reconcile the psychological theory of the business cycle with the findings of the preceding pages, we need then to assume that the variations of solar activity affect directly, or through some terrestrial mechanism, the psychological reactions of human beings. It is not necessary to claim that the influence is continuous (tho that would not be impossible), but only that it sets in when the psychological wave of optimism has been well under way for years and has created in itself all the elements for the next phase of the business cycle; when, as Pigou says, the boom is at its maximum and the

8. A. C. Pigou, Industrial Fluctuations, London, 1927 and 1929.

mass psychology at high pitch. Then some great disturbance of the solar activity can affect mass psychology, which is in a receptive mood, and can produce a "brainstorm," the start of the wave of pessimism that, according to Pigou's theory, will engender in itself all the characteristics of the depression phase of the business cycle.

The latest investigations of the solar-terrestrial relationships point in this direction. Biology is the last one to be added to the long list of sciences in which the solar cycle manifests an influence. The correlation between birth and death rates and the main waves of business fluctuation is a well-known and established fact in the field of the social sciences. The usual explanation has always been that business conditions affect demographic phenomena, in other words that the business cycle is a *cause* of cycles in vital statistics. But some doubts have arisen recently about this connection. We have seen in the preceding discussion of Huntington's theory that the correlation between business cycles and death-rate cycles actually exists but is the *reverse* of the one Huntington thought logical. Now that we have seen that business cycles follow the solar cycle, we naturally are inclined to believe that the "logical" correlation between death rates and business is due to the fact that the sun is at the same time and by different channels influencing both phenomena.

With respect to the birth rate the direct correlation existing with business seems logical; no one can deny that business affects marriage rates. But this cannot explain the entire matter, if we are to give credence to a study made not long ago by M. B. Hexter, who found that the curve of conceptions *preceded* the fluctuations of business activity. The discovery so bewildered its author that he found no way out of it other than to suggest that the psychological reaction of prospective fathers in their daily business was the cause of the business cycle.[9]

In animal life some correlations with the solar cycle have also been known, particularly the one disclosed by the Hudson

9. Maurice B. Hexter, Social Consequences of Business Cycles, Boston, 1925.

Bay Company's record of the trapping of rabbits; but it was generally explained by the physical action of the solar rays on the vegetable world that feeds the rabbits, and not through a direct physiological connection.

Perhaps the first observation of direct biological effect[1] was the investigation of J. Vallot, Director of the Mont Blanc Observatory, in collaboration with two physicians.[2] According to the report presented by them to the Academy of Medicine of Paris, they started their investigation after it was found impossible to explain on meteorological grounds the sudden changes in the course of chronic illness that they observed in the hospital. Those "accidents" often happened to patients without any apparent relation to the previous cause of the sickness, and at the same time to patients with very different kinds of diseases.

To investigate the possibility of a cosmic cause, the two physicians kept a record for nine months of the daily course of the illness of 237 patients, noting the sudden changes and classifying them according to their intensity. At the same time an astronomer took daily observations of the passage of sunspots through the central meridian of the sun, i.e. when they pointed directly at the earth. The result of the comparison of the two different sets of observations was that tho there were sunspots only 29 per cent of the time, 51 per cent of all the disturbances recorded in the condition of the sick occurred during this period; and counting only the major disturbances ("accidents aigus"), 72 per cent of them occurred on days with spots.

1. We quote this as the first investigation we know, altho we are aware that the suggestion of the direct relation between solar activity and human affairs has been offered by many writers, but in a more or less literary way without adding individual investigations on the problem. Of them we shall quote the Frenchman Th Moreau in several publications and in various parts of his book, Les Énigmes de la Science, Paris, 1925; and the Russian Professor Chijevsky, of whose suggestion of the electric nature of the relationship we shall have something to say later.

2. "De l'influence des taches solaires sur les accidents aigus des maladies chroniques," by J. Vallot, G. Sardou and M. Faure, Bulletin de l'Academie de Medecine, Paris, 1922, Tome 88, p. 41.

These researches have been continued in France up to the present day, and several publications have appeared concerning them. G. Sardou maintains that direct connection has been detected also in cases of psychical and mental disturbances.[3] Dr. Maurice Faure has been so interested lately in this research that he is now directing an International Institute "pour l'étude simultanée des actions solaires et de leurs effets biologiques."[4]

This kind of investigation on biological effects seems to be retarded by the same difficulty that is holding back other researches on the daily relationship of solar and terrestrial phenomena, i.e. that the origin of the solar activity which produces the disturbances is not known, because sometimes it is associated with spots and at other times seems to come from faculae or prominences or invisible disturbances. S. Chapman, in the latest report of the Committee on the Relationship between Solar and Terrestrial Phenomena, sums up the investigation of the relationship with terrestrial magnetism. He states that altho the severe magnetic storms are associated with large sunspots, other spots bring no effects; and that "there must exist on the sun's surface certain restricted areas — which we have ventured to designate M-regions. . . . They cause terrestrial magnetic disturbances probably by emitting well-defined corpuscular streams. Such solar regions in the individual sense escape the usual astrophysical method of observation."[5]

A. Nodon, a French astronomer who has lately been studying those invisible regions (he calls them "foyer électriques"), has pointed out that their delimitation will solve also the problem of the biological actions in which he is a believer. Recently he has stated that he has undertaken an investigation of the relations of those electrical solar centers with vegetable phenomena and pathological disturbances in human beings,

3. "L'Effet des Taches Solaires sur l'Homme," by Gaston Sardou; La Revue Universelle, August, 1929, Paris, p. 244.

4. Cited by A. Nodon. See note 6 infra.

5. International Astronomical Union, Transactions, vol. iv, 1932. The Committee is maintained by the International Research Council.

at the University of Bordeau, in collaboration with the biologist, Dr. Cuvier.[6]

We may now turn to the possibilities of the mechanism of the relation. If a direct relation exists between the focus of disturbance on the sun's surface and the biological phenomena on the earth, it may take several forms. Without being committed to any of them, as the whole subject is outside our competence, we shall merely point out two possible explanations of the mechanism of the direct relationship, if any, between solar and human phenomena.

(1) The mechanism of the relationship may be due more or less to the direct action of the solar rays. Solar radiation is composed of many different rays, of which the visible light accounts for less than 40 per cent, the rest being distributed between the ultraviolet and the infrared.[7] While the total energy of the sun's rays varies only 2½ per cent between the maximum and minimum of the cycle, the variations are unevenly distributed between different parts of the spectrum. In the ultraviolet section of the spectrum alone the variations are so wide that, as contrasted with a maximum variation in the sun's rays of only 2½ per cent, the ultraviolet light received by the earth from the sun was in September, 1929, for example, almost 39 per cent greater than it was in June, 1932.[8] In some parts of the spectrum in this zone the fluctuation is even greater. C. G. Abbot, a well-known authority on the subject, says: "Petit, observing with the narrow band of ultraviolet rays at 3.160 Å [316 millimicrons] finds alterations of over 100 per cent in their intensity. This means that if our eyes were sensitive to such rays alone we should find the

6. "Recherches sur l'action des centres actifs du soleil," by Dr. Alfred Nodon, in Revue Scientifique, Paris, February, 1934, p. 103.

7. Ultra-Violet Radiation, by M. Luckiesh, New York, 1922, p. 23.

8. This phenomenon is measured by the Mount Wilson Observatory by the relation between the ultraviolet zone of the spectrum to the green zone. This ratio was 1.24 in September, 1929, and .89 in June, 1932 As the green zone, being part of the visible part of the spectrum, varies by less than 2½ per cent, it is used to measure, by comparison, the variation in the ultraviolet zone. See the quarterly Bulletin for Character Figures of Solar Phenomena. International Astronomical Union, Eidgen Sternwarte, Zurich.

sun's surface twice as bright at some times as at others."[9]

The relation between the sunspots and the ultraviolet ray fluctuations has sometimes been explained by the effect of the electrical particles emanating from the sunspots. As they reach the higher zones of our atmosphere and strike oxygen atoms, they form ozone; and this layer of ozone (the well-known Heaviside-Kennelly layer which, acting as a reflector, makes long-distance radio transmission possible) acts as a screen, absorbing the ultraviolet rays of less than 290 millimicrons of wave length, thus preventing access to the earth's surface of part of the longer ultraviolet rays. Thus the number of sunspots makes a great difference in the ozone layer, and controls the amount of ultraviolet rays that reach us. In some periods a clear correlation between the sunspot curve and the ultraviolet fluctuations is apparent.[1]

C. G. Abbot has emphasized the importance of the control of this ray by the ozone layer, stating that if the ultraviolet rays of less than 290 millimicrons were allowed to reach us, they would destroy human sight and tissues, while if the screening effect extended to the rays of 320 millimicrons, human and animal young would languish with the enfeebling disease of rickets.[2] But it is also true that this part of the solar radiation is easily absorbed by fog and smoke. There is a possibility of its action in the ionization of the atmosphere, and, according to an investigation by the Harvard School of Public Health, an experimental changing of the quantity of ions in the air absorbed resulted in records of agreeable or disagreeable sensations, depending upon the electrical charge of the ions.[3] But as the research was done with ionizations far greater than normal atmospheric values, perhaps its only value for our purposes is that it is indicative of a possibility. The other possibility of an indirect action of the ultraviolet

9. Smithsonian Institution, Annual Report, 1927, p. 163.

1. "Measurements of Ultra-Violet Solar Radiation," by E. Petit in the Astrophysical Journal, vol. 75, p. 193.

2. Smithsonian Institution, Annual Report, Washington, 1927, p.163.

3. C. P. Yaglou, A. D. Brandt and L. C. Benjamin, Physiologic Changes during Exposure to Ionized Air. Result of research conducted at Harvard University School of Public Health, Boston, 1933, p. 7.

rays is the one suggested by Abbot. "Ultraviolet rays produce certain changes of chemical structure in fats and oils which are the source of those traces of hormones so extraordinarily important, all out of proportion to their infinitesimal occurrence in the growth and health of animals."[4]

The rays of the other part of the spectrum, infrared and heat, tho they have more penetrative force, fluctuate very little during the solar cycle. But experiments have been conducted lately in England, by Sir Leonard Hill, upon the psychological effect of the infrared rays.

(2) The mechanism of the relation can be of an electrical nature, and a more or less direct one. It is known that one of the clearer terrestrial effects of the solar variation is found in a cycle of similar length in the magnetic activity of the earth. The effect of the severe magnetic storms associated with the appearance of large sunspots upon telegraphic wires and electrical appliances is one of the most clearly established facts in solar-terrestrial relations.[5] The suggestion of a direct electrical effect upon human beings has perhaps been the first one to appeal to the men who had thought of the possibility of a direct relationship. Professor Chijevsky of Moscow University, in a lecture given in Philadelphia in 1927, referred to the possibility of the electrical influence of sunspots' "upsetting the electromagnetic equilibrium of men," and giving origin to waves of mass psychology.[6] A similar suggestion had been offered in 1925 by Th. Moreau.[7]

The electrical hypothesis had very little utility, however, until the existence of electrical currents in the human body was scientifically proved. This was accomplished in 1929 by E. D. Adrian, a Nobel Prize winner and the outstanding researcher in this new field of electrophysiology. His pro-

4. Smithsonian Institution, loc. cit., p. 163.

5. See F. Sanford, Terrestrial Electricity, Stanford University, 1931, chapter VI on Magnetic Storms and Solar Activity.

6. Reproduced in The Sunspot, Santa Clara Observatory, California, March, 1927, vol. 13, No. 2. He published his theory in Russia in 1922, according to Pitirim Sorokin, Contemporary Sociological Theories, New York, 1928, p. 126.

7. Th. Moreau, Les Énigmes de la Science, Paris, 1925, p. 42.

cedure consisted of connecting a severed nerve to strong amplifying tubes and recording instruments. The curious fact was discovered not only that the messages carried to the centers were electrical, but also that they "are scarcely more complex than a succession of dots in the Morse code."[8] For instance, in an experiment on the nerve of a cat's toe, the potential changes, of the order of 15 microvolts, were formed in any one fiber by waves of the same kind varying only in the changes of frequency and duration of the discharge as they expressed light touch, heat, severe pressure, etc.[9]

Perhaps the strongest proof was offered by the experiment made in 1930 by E. G. Wever and C. W. Bray. They "connected the auditory nerve with an amplifier and telephones and they were rewarded by a surprising result. Any sound reaching the ear was reproduced in the telephones: speech could be understood and the speaker identified by his voice and notes of high as well as low pitch were rendered without distortion. Clearly something was acting as an efficient microphone, translating the sound oscillations in the cochlea into electrical oscillations in the circuit leading to the amplifier."[1]

The eminent biologist, Sir Leonard E. Hill, admits that altho the nature of the impulses remains undetermined, the fact seems to be established that the form of energy concerned is electrical.[2]

Among the hypotheses concerning the mechanism of the direct link between solar variation and changes in human psychology, it is impossible now to make a choice. Neither do we believe that it is possible, until far more evidence is accumulated, to prove that the social relationship exists at all. The only thing now allowable is to treat the conclusions

8. E. D. Adrian, The Mechanism of Nervous Action. Electrical Studies of the Neurone, Philadelphia, University of Pennsylvania Press, 1932, p. 12.

9. Ibid., p. 8.

1. Ibid., p. 37.

2. Sir Leonard E. Hill, Philosophy of a Biologist, London, 1930, p. 46.

of natural science as working hypotheses for our purposes. On this basis the investigations which are detailed in the following pages have been carried out.

If we observe Chart VI,[3] we see that altho the solar curve coincides with all the major business depressions, there are at least two of the short-period business panics — short ones but sharp — that have no relation to the solar curve. These are the "rich man's panic" of 1903–04 and the recession of 1913–14. Both occurred when the solar curve was above normal.[4]

Curiously enough, these two periods (1903–04 and 1913–14) coincide with periods of a sharp drop in the earth's average temperature which has been clearly connected by meteorologists with a diminution of the solar radiation received. But the link of connection was through an earthly rather than a solar phenomenon. In May, 1902, the great eruption of Mount Pelee in the Antilles cast into the upper layers of the atmosphere thousands of tons of volcanic dust, which, distributed within a few months around the earth by the stratospheric winds, remained aloft for many months, reducing considerably the radiation that came from the sun. The reason for this is that the volcanic dust in the upper atmosphere is thirty times more effective in shutting off solar radiation than it is in keeping terrestrial radiation in,[5] thus producing an inverse greenhouse effect.

H. H. Kimball has published a record of these disturbances of atmospheric conditions as a result of volcanic eruption, as reflected in the curve of the readings of the pyrheliometer (an instrument that measures the total heat of sunshine) at the stations of the northern hemisphere of the earth. In this record there is a sharp drop of the pyrheliometric curve at the

3. P. 22.

4. Additional evidence of the absence of connection with the solar cycle is given by the fact that the mean latitude of the sunspots in those four years was above 15°. We have seen above that of the other fifteen years, in the sixty-year record of American business, that were associated with similar solar conditions, ten of them were years of prosperity and the other five normal or near normal.

5. W. J. Humphreys, Physics of the Air, New York, 1929, p. 576.

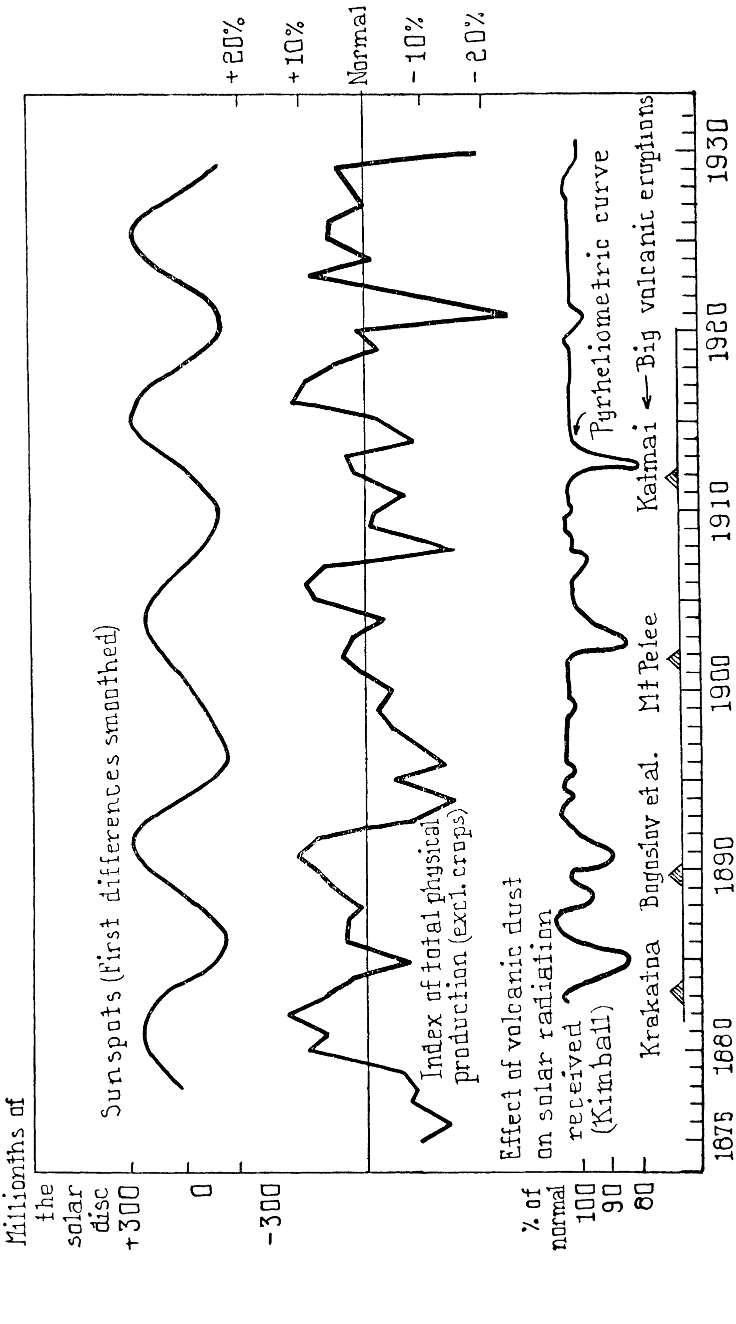

Millionths of the solar disc
+300
0
-300
% of normal
100
90
80
+20%
+10%
Normal
-10%
-20%
Sunspots (First differences smoothed)
Index of total physical production (excl. crops)
Effect of volcanic dust on solar radiation received (Kimball)
Pyrheliometric curve
Krakatoa
Bogoslov et al.
Mt Pelee
Katmai
Big volcanic eruptions
1875
1880
1890
1900
1910
1920
1930

CHART VIII

end of 1902, remaining low in 1903 and going back to normal at the beginning of 1905. The next drop of this atmospheric curve is the one due to the great eruption of Katmai in Japan, in June, 1912. The curve returns to normal at the end of 1914, and since then it has not noticeably varied.[6]

The two previous great volcanic eruptions that had a similar effect on meteorological records were the Krakatoa eruption of 1883, which made a low in the pyrheliometric records, centering in 1885, and the eruptions of Mount Bogoslov and other volcanoes in 1890, which were related to a low of the meteorological curve at the beginning of 1891. These dates coincide with the depression of the eighties and the Baring panic of 1891, which was the beginning of the long depression of the nineties; but both periods were also lows in our solar curve, as can be seen in Chart VIII, and the dates imply nothing inconsistent with the general reasoning. Perhaps the fact that the business curve on our chart came down in the cycle centering in 1891 before the solar curve and not later, as in the other cycles, can be traced to this atmospheric factor. A similar argument can be used to explain the fact that the business curve makes a low in 1885, a year before the solar low.

It is interesting to note that since 1917, a period in which no great eruptions have altered atmospheric conditions, the business records show a clear case of an 11-year business cycle between the two bottoms of the depressions in 1921 and in 1932.

Humphreys cites the year 1815–16 as the best case of volcanic interference with solar radiation. It was the remarkable "year without summer," and the curve of world temperature reached the lowest point of the century in 1816, after the big eruption of Tomboro in the East Indies.[7] The amount of

6. H. H. Kimball, "Solar Radiation as a Meteorological Factor," in Monthly Weather Review, December, 1931, p. 472. In April, 1932, a great volcanic eruption occurred in the Andes between Argentina and Chile, and its effect has been noticeable in the measurements of solar radiation in the southern hemisphere in 1933. But whether its effect all over the world is comparable to the eruptions cited above is a matter of speculation until all the world records are analyzed.

7. Op. cit., p. 594.

material yielded by this eruption has been estimated at 36.4 cubic miles.[8] According to the conspectus of Dr. Thorp,[9] there was a sharp recession in the United States and in England in the middle of 1815, and the year 1816 was recorded as "depression" for the two countries. The next case in the Humphreys chart is the Cosequina eruption, with a definite low in the curve in 1837, and again the conspectus shows an evident recession of business in the two countries during that year.

All this is mentioned merely as additional evidence for the solar hypothesis. Many economists have noticed the difference between short "panics" and long "depressions," and some European economists, such as Bouniatian, have stressed the importance of studying them apart as different phenomena. In the period considered in our investigation, there appears to be a correlation of the long depressions with the 11-year solar cycle, and of the short panics with the accidental drops of the solar radiation received on the earth as a consequence of great volcanic eruptions; furthermore, in some cases the combination of both actions may explain longer depressions.

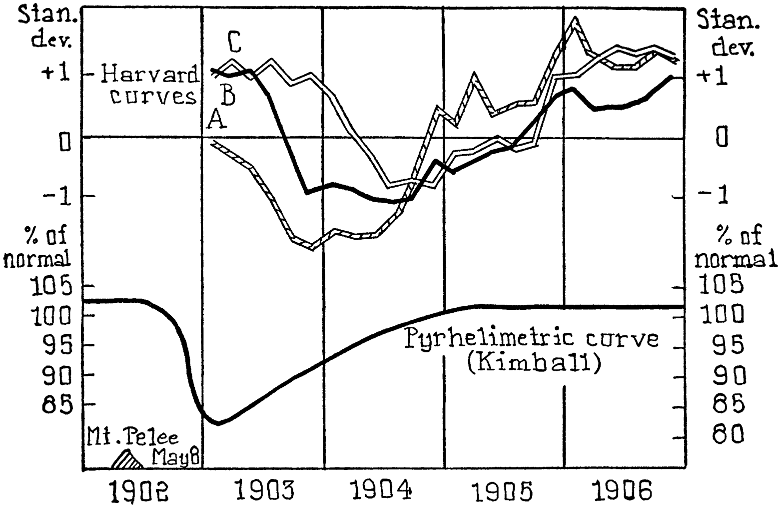
We may turn now to the idea of Warren M. Persons and his Harvard associates concerning the lag between speculation and business. In the cases of the "rich man's panic" of 1903 and the 1913 panic, the action of the meteorological curve was analyzed in detail in relation to the A, B and C Harvard curves (see Chart IX). According to the Kimball chart,[1] the pyrheliometric curve began its downward course in the middle of 1902, several months after the eruption, and reached its lowest point in the first quarter of 1903, then recovered and returned to normal at the beginning of 1905. The Harvard A curve began its drop in the last quarter of 1902,[2] and remained

8. G. W. Tyrrell, Volcanoes, London, 1931, p. 91.

9. W. L. Thorp, Business Annals, New York, 1926, p. 94.

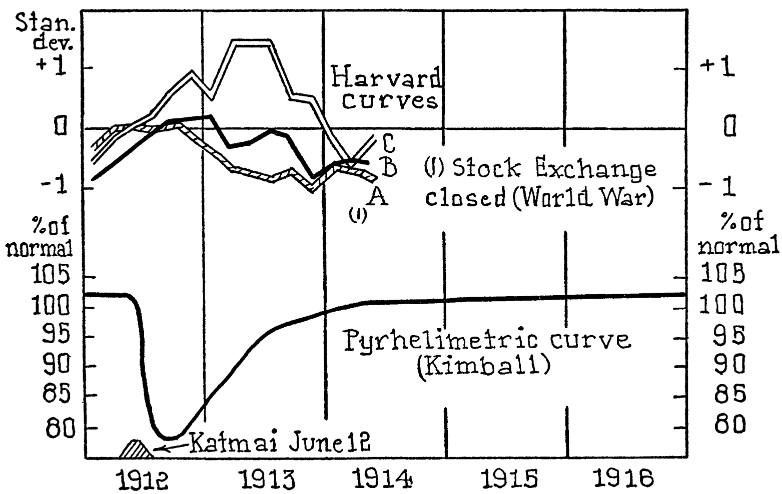
1. H. H. Kimball, "Volcanic Eruptions and Solar Radiation Intensities," Monthly Weather Review, August, 1918, p. 356.

2. No Harvard curves are available till January, 1903, but the fact here referred to has been taken from the behavior of the Persons stock prices curve.



Stan. dev.
+1
0
-1
% of normal
105
100
95
90
85
80
Harvard curves
C
B
A
Pyrhelimetric curve (Kimball)
Mt. Pelee May 8
1902
1903
1904
1905
1906

a



Stan. dev.
+1
0
-1
% of normal
105
100
95
90
85
80
Harvard curves
C
B
A
(1)
(1) Stock Exchange closed (World War)
Pyrhelimetric curve (Kimball)
Katmai June 12
1912
1913
1914
1915
1916

b

CHART IX

down until the last quarter of 1903, recovering sharply, especially in the second half of 1904. It is therefore obvious that the meteorological curve preceded the Harvard A curve, but the shape of the two is very different. Altho logically it could not be expected that the A curve would recover as sharply as the physical curve, the evidence is inconclusive. In the 1913 panic there appears to be a similar lag — the meteorologic curve falls sharply in June, 1912, while the Harvard A curve begins its dive in the last quarter of the same year. The meteorologic curve recovered quickly as in the previous case, and at the end of 1917 it was back to normal. But the Harvard A curve, after touching bottom at the end of 1913, remained below normal until the stock market closed in July, 1914, on account of the Great War. The confusion of this event, therefore, plays a large part in the value of our comparison. The cases of the Krakatoa (1884–85) and the Bogoslov (1890–91) eruptions were not analyzed because they fell in periods in which the depression was expected in any event because of the position of the solar curve.

Perhaps a detailed analysis of the economic features of the "rich man's panic" as compared with a clear case of a depression seemingly associated with the solar cycle (1921 or 1932, for example) will solve the question as to whether or not there is a structural difference between both types of business recessions, as some continental economists maintain[3] and as the solar hypothesis seems to require.

It is worth while to note also that similar occurrences in the past, such as the striking case of the "year without summer" cited above, could be offered as an explanation of the fact — noted by Jevons — that in economic history there are cases of panics which "will not fall into the decennial series."[4] Jevons stated that this was not inconsistent with his theory, because he admitted the possibility, which no one can deny, of political or other causes as a source of financial panics.

Humphreys has demonstrated that by adding the fluctuations in the pyrheliometric curve (which portrays volcanic

3. See M. Bouniatian, Les crises industrielles, Paris, 1922, p. 44.
4. Investigations . . . , loc. cit., p. 233.

disturbances) to the sunspot cycle, a curve can be made which correlates well with the changes of the mean world temperature deviations.[5] This raises the question again whether the correlations obtained with business curves are only a consequence of a connection through temperature, and whether the "missing link" (tho it cannot be through weather and crops) might be of some indirect kind, perhaps analogous to the suggestion of Huntington concerning health.

The point was investigated and the following facts were disclosed:

(1) In temperature fluctuations for the whole world, the volcanic dust factor is the most important one. The small deviations above normal seem to be related to periods of sunspot minima, but all the sharp drops in temperature are clearly related to volcanic eruptions. This is even more clear in the curve of the temperature in the Eastern United States which shows for the period 1880–1913 only the four drops corresponding to the four big eruptions detailed above.[6] On the contrary, in the business curve, as we have seen, the solar cycle is the main factor, and the volcanic dust disturbance a secondary one.

(2) Graphic correlations showed that the connection between temperature and business curves was very small in comparison with the high correlation obtained between solar and economic curves. Progressive smoothing made the correlations grow smaller and disappear instead of making them increase as was the case in the solar-business comparisons, thus showing that the main cyclical factors were different in both curves, which agrees with the findings of the preceding paragraph.

(3) The solar factor in the world temperature curve is the curve of the total amount of sunspots, while in the business curve it seems to be the increase or decrease of sunspots, as shown in previous pages.

Therefore, in the light of these results, the suggestion of an

5. Humphreys, op. cit., p. 590.
6. Idem, p. 312.

indirect connection was discarded and the investigation pushed forward following the hypothesis of a direct one.

In working out this hypothesis, the comparison of business fluctuations of less than a year with similar series of solar phenomena seemed to be logically the next step.

For the period since 1920 there is available a good index of solar radiation based on records kept by the Smithsonian Institution's Observatories, which are located in different parts of the world[7] in order to obtain a true average. The Smithsonian Institution also has published since 1920 mean values of the "preferred solar-constant." These values are given in calories per square centimeter per minute, the normal value being around 1.940 calories but fluctuating continuously. Dr. Abbot believes that the variation of monthly mean values of the radiation of the sun is really a combination of a small number of regular periodicities, as shown in a chart in which the solar-radiation curve is reproduced by seven curves (not sine curves) of 68, 45, 25, 21, 11, 8 and 6⅔ months. In accord with this hypothesis he has been issuing forecasts of the solar variations two years in advance,[8] which he hopes will be useful some day for weather forecasting.

To eliminate the influence of seasonal variation,[9] it appeared to be the best procedure to construct a 12-month moving average of the "preferred-solar-constant" for the period 1920–32.[1] When plotted as deviations from the normal value, the curve showed plainly not only the 11-year type of fluctuation but also a clear and predominant fluctuation, with waves inside of it forming three well-defined cycles with lengths of 46, 33 and 47 months respectively. When compared with one of the best known indexes of business activity in the United States — that of Col. L. P. Ayres — the same mathematical procedure was followed (12-month mov-

7. In Arizona, South Africa and Northern Chile.

8. See the last one, "Forecast of Solar Variation," by C. G. Abbot, Washington, 1933 (Smithsonian Misc Collections, vol. 89, No 5).

9. Annals of the Astrophysical Observatory of the Smithsonian Institution, vol. v. C. G. Abbot and others, Washington, 1932, p. 252.

1. Data for the same, Annals . . . , p. 278; data for 1931–33 obtained by courtesy of Dr. Abbot.

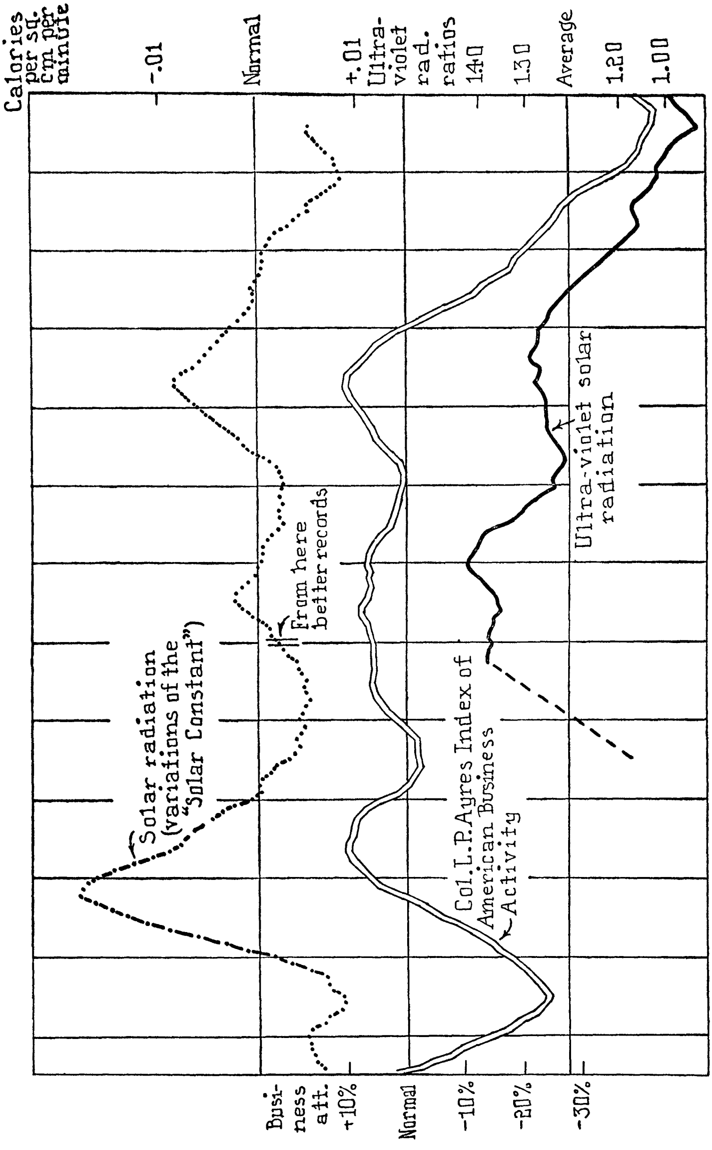
ing average) in order to make the comparison possible. The result was strikingly high inverse correlation. A correlation was expected in the main feature (i.e. in the 11-year fluctuation), but the agreement of the three small cycles with similar ones in the business curve was unexpected.The result can be seen in Chart X, in which the solar-radiation curve is plotted upside down to help visualize the inverse correlation. A coefficient of correlation, if calculated, will show a high value, but it was not calculated because, according to Dr. Abbot,[2] the solar values prior to 1926 are not strictly comparable, nor so good as those taken after that date with better apparatus and stations more advantageously located. For this reason, the different shape of the first solar-radiation cycle (1921–24) as compared with the following cycles perhaps should not be considered as a real variation of the amplitude of the waves.

Another comparison between business and solar data was made employing an index computed since August, 1924, by the Mount Wilson Observatory. This is an index of a part of the solar spectrum, the ultraviolet rays, which, it will be remembered, vary within a much wider range than the total solar radiation curve. This index was reduced to a 12-month moving average to make it comparable with the rest of the chart.[3] Altho the period is so short that nothing statistical can be deduced, the existence of a direct correlation with the business curve is apparent.

Let us now take up, therefore, the concluding portion of our investigation in its present stage and note what light it throws upon the relation between human psychology and the business cycle. The psychological theory of the cycle,

2. Idem, p. 255.

3. The monthly data were taken from the "Bulletin for Character Figures of Solar Phenomena," of the International Astronomical Union. The necessity of the 12-month moving average was confirmed by the existence of a clear seasonal variation, because when the original data were arranged as percentages of the 12-month moving average values and the monthly averages for the whole period were taken, it showed a clear type of seasonal fluctuation with a minimum of 94.2 in August, against a maximum of 107.2 in January. The existence of this fluctuation was suggested to us by Dr. Abbot.



Calories per sq. cm per minute
-.01
Normal
+.01
Ultra-violet rad. ratios
140
130
Average
120
1.00
Busi-ness att.
+10%
Normal
-10%
-20%
-30%
1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932
Solar radiation (variations of the "Solar Constant")
From here better records
Col. L. P. Ayres Index of American Business Activity
Ultra-violet solar radiation

CHART X

as we have seen above, explained it by the appearance of alternating waves of optimism and pessimism, which, coming one after the other, operate to determine the turning points in business conditions. It is precisely this transition from optimism to pessimism which in the speculative community is referred to as "the passing from a bull to a bear psychology."

The last depression affords an almost perfect example of a condition described in these terms. The movement of stock prices during the past few years can be said to represent one of the best indices we have of the state of public psychology, and of the dating of its turning points. Prior to 1925, the number of persons speculating in the stock market was comparatively few, if the number of shares traded can be taken as a fair criterion. The daily volume of business on the stock exchange very seldom rose substantially above a million shares, and a large part of these transactions were made by professionals, who are popularly supposed to be on their guard against falling in line with mob psychology. After the end of 1924, the increase in the number of stockholders and in the volume of transactions on the New York Stock Exchange was prodigious, the latter increasing from around 200,000,000 shares a year in 1925 to over one billion shares in 1929,[4] during which year it reached the staggering total of 16,000,000 shares in a single day. It is common knowledge that people from all walks of life and every station of society participated in what is now generally agreed was — considering the number of persons and transactions involved — the greatest speculative mania of modern times.

The bursting of this speculative bubble at the end of 1929 affords an excellent opportunity for something analogous to an experiment on the correlation of turning points in solar and speculative activity. Stock prices had experienced an extraordinary rise from a level of around 100 in 1924 to approximately 320 in the first half of 1929, according to the

4. For the details of the number of stockholders and the volume of transactions then made, the reader is referred to the forthcoming study of Stock Markets by the Twentieth Century Fund, of which a summary, entitled Stock Market Control, is already in print.

Dow-Jones average of 30 industrial stocks. The possibility of a serious break in stock prices was repeatedly broached by financial commentators and by the Federal Reserve Board. Notwithstanding these facts, however, after a vacillation of six months the market began a new rise, and in June, July and August of 1929 the Dow-Jones index added 60 points, increasing to a level of 380 in the early part of September. Then suddenly, and with increasing momentum, speculators, seized with panic, proceeded to dump their holdings. How the whole structure went to pieces in two months is sufficiently well known. We may stress the point here, however, that the piling up of a new layer of optimism upon the top of a prolonged rise of stock prices, notwithstanding all the warnings, and the sudden change from unbounded optimism to frantic pessimism are extremely difficult to explain on "rational" grounds.

With this in mind, we compared monthly data of speculation in 1929 with variations in solar phenomena for the same year. Based on the results of the preceding pages the monthly measurements of the "solar constant" seem the best solar data with which to begin. For an index of American speculative sentiment, we chose Professor W. L. Crum's index of industrial stock prices, known as "Barron's Averages," because they "are constructed to portray the speculative movement of stock prices rather than the trend of investment prices."[5] The Barron's Averages were converted to monthly figures to make them comparable with the "solar constant preferred values" because the latter cannot be reduced to a weekly basis. The two curves are shown in Chart XI. The solar-constant values are inverted in accordance with the general inverse correlation which preceding pages revealed to be the case. A glance at the chart will show a striking similarity in the date of the turning points. Furthermore, contrary to expectations, the behavior of the two curves during the *whole* year is similar. The solar constant, after remaining on a level far above normal value during the first half of

5. "The Dow-Jones Averages and the Barron's Averages," published by Barron's, New York, 1932, p. 116.

the year, reached a value farthest away from normal, and then came sharply back to normal in November and December. This sharp three-month movement, amounting to 0.013 calories per square centimeter, is the greatest three-month movement that the solar-constant values have had since 1926.[6]

When a coefficient of correlation for the two curves was calculated, it yielded a value of −.886, a very high value when it is considered that −1.00 would mean *perfect* inverse correlation.

Because of the fact that the London Stock Market in 1929 made its turning point at the same time as the New York Market, the monthly values of an index of London common stock prices (the "Banker's Magazine" Index) were compared with the solar curve, and the result was an even higher correlation, notwithstanding the fact that the London prices are supposed to portray investment movements more than speculative activity. These data are also shown in Chart XI. The coefficients of correlation between the three curves are as follows:

London and New York stock prices..................	$+.919 \pm .029$
Solar radiation and New York stock prices	$-.886 \pm .042$
Solar radiation and London stock prices...	$-.909 \pm .034$

Looking for the reasons for the sharp movement in the solar constant values in September and December, 1929, we found that there was actually an upheaval in the sun, according to all the records available. The mean daily areas, computed by the Greenwich Observatory for periods of 27 days (in order to cover a whole solar rotation),[7] give the fewest number of spots in 1929 in the solar rotation No. 1016, between August 28 and September 24, with a mean daily area of spots of 273 millionths of the sun's hemisphere; and in the following rotations the solar spots increased tenfold, reaching the maxi-

6. The comparison cannot be made from periods further back because the previous values are not strictly comparable in amplitude, as has already been explained.

7. Taken from Monthly Notices of the Royal Astronomical Society, vol. xc, p. 303.

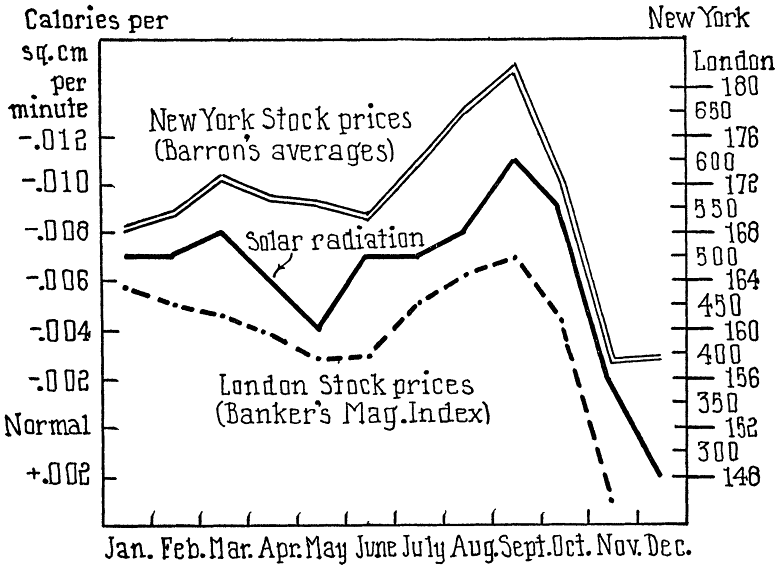


CHART XI

mum figure of 3082 millionths of the solar hemisphere in rotation No. 1019, between November 18 and December 15. A similar action is apparent in the records of the solar faculae. From the figures of the International Astronomical Union, which has detailed daily records for studies of solar-terrestrial relationships of the spots in the central zone of the sun, we find that in this zone (which is just in front of the earth) there were very few spots during September, 1929, there being some days when no spots at all were recorded. In the following month, this zone was covered with spots. Thus, the difference between the September mean figure and that of December was the greatest three-month change in spottedness recorded in the central zone since 1917,[8] when the measurements were begun. These spots were big enough to be visible to the naked eye, and various contemporary publications

8. Bulletin for Character Figures of Solar Phenomena, Zurich. See October-December, 1929, and previous numbers.

gave an account of the phenomenon.[9] We have emphasized this *change* in the spottedness, having in mind the quotation of Bauer cited earlier in this paper, to the effect that this is the most important from a terrestrial point of view.

Let us now direct attention to the opposite side of the picture, and consider the turning point from depression to the beginning of a rise in its relation to the curve of solar activity. In particular, let us consider the question why the revival in stock prices which took place in the first quarter of 1932 did not continue, but instead was followed by a sharp drop which did not reverse itself until July of that year. Solar-constant values exactly comparable to those we have used for 1929 are not available because the observations of the Chilean Station, the most important one of the Smithsonian Institution, were discontinued in April, 1932, on account of the eruption in the Andes. But the sunspot records show clearly a phenomenon, the inverse of that of 1929. The Greenwich measurements of sunspot areas show that the higher values of 1932 were reached in the rotations No. 1052 and 1053, from May 6 until July 27, with 367 and 363 millionths of the sun's visible disc covered with spots. Then the solar surface became cleared, and three rotations later the average went down to only 15 millionths of the sun's disc (rotation No. 1057, from September 19 until October 16).

The same thing can be said about the Greenwich figures of area of solar faculae.

This fact is even clearer in the Relative Sunspots Numbers for the central circle zone, of which monthly data are available, and they have the advantage of representing not all the solar surface but only the central zone that affects the earth most.[1] This index can be seen in Chart XII.

It is known that the lowest prices for common stocks in the New York and London Stock Exchanges were reached in the

9. "Naked-eye Sunspot" in Nature, December 28, 1929, p. 998. Also December 7, 1929, p. 888. A picture of the sun in November, 1929, can be seen in The Monthly Evening Sky Map, Brooklyn, February, 1930, p. 2.

1. Bulletin for Character Figures . . . , Nos. of 1932 and 1933, Zurich.

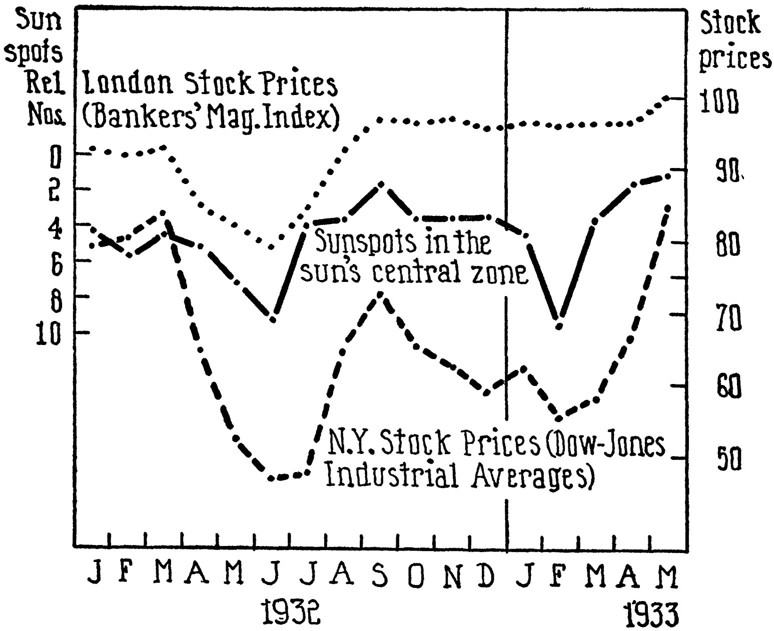


CHART XII

first half of July, 1932, as can be seen from Chart XII, in which New York stock prices are pictured by the "Dow-Jones" average of industrial stocks,[2] and the London prices by the Bankers' Magazine Index. The graph shows the curious fact that the recession in the last quarter of 1932 is also visible in the solar curve. And it is interesting to note that the solar curve, as shown on Chart XII, makes a second low in February, 1933, turning up again in the following months. Altho this is a fact, too much should not be expected of comparisons for the year 1933 because, except for clear solar changes which are sudden and which can be associated with the turning points, it is too much to hope for an exact month-to-month correlation. In the years in which the speculative curves moved steadily up or down, such as in 1930–31 and

2. We could not use the same index as in the previous chart because it has been discontinued. The index used was taken from The Dow-Jones Daily Averages, New York, 1934.

previous to 1929, no clear month-to-month relation has been found between solar and speculative short swings, except for the seasonal movements of the speculative curve in the down swing, which perhaps can be associated with the similar seasonal variations of the solar-terrestrial physical curves such as magnetic activity and aurora borealis.

By way of conclusion, we wish to repeat that the results of this paper are not supposed to be in any sense final. The results are so striking, however, that it is thought desirable to publish them in their present preliminary stage in the hope that other investigators may be encouraged to do further work along the same lines and contribute suggestions and criticisms. In particular, it should be noted that the aspect of this subject which requires the most careful attention is that which concerns the direct effect of various manifestations of solar activity upon the psychological attitudes of human beings. The value of the high correlations obtained depends upon the proof of the validity of a direct causal relation between solar and human activity.

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