WHEAT STUDIES

of the FOOD RESEARCH INSTITUTE

VOL. XVIII, NO. 7 (Price $1.00) APRIL 1942

VARIABILITY IN WHEAT YIELDS AND OUTPUTS

PART I. CYCLES OR RANDOM FLUCTUATIONS

V. P. Timoshenko

Variability in wheat yield and output is an important subject in itself, but its study is of even greater importance for a better comprehension of fluctuations in agricultural production as a whole, and fuller understanding of these is highly necessary for students of general economic fluctuations.

Are fluctuations in wheat yields and outputs systematic in some respects and consequently predictable to a certain extent, or are they wholly dominated by chance? This is the central question here considered. The answer is that many fortuitous factors, of which weather is perhaps the most important, dominate fluctuations in regional yields and outputs of wheat, at least to such an extent that, even with close statistical scrutiny, it is difficult to detect systematic tendencies.

The usual analysis of series on wheat yields and production into component parts, however, reveals "cycles" with an average duration of about 3½ years, which recur less irregularly than cycles in business. The amplitudes of these oscillations, though varying greatly from region to region, are large enough in the major wheat-exporting regions to be of great economic importance.

Cycles of 3 or 4 years are also characteristic of fluctuations in other crops, and they are the most frequent in business cycles. However, the relatively frequent occurrence of cycles of much longer duration in business oscillations indicates their greater divergence from random fluctuations than may be said of fluctuations in wheat yields and outputs.

STANFORD UNIVERSITY, CALIFORNIA

WHEAT STUDIES
OF THE
FOOD RESEARCH INSTITUTE

Entered as second-class matter February 11, 1925, at the Post Office at Palo Alto, Stanford University Branch, California, under the Act of August 24, 1912.

Published eight times a year by Stanford University for the Food Research Institute.

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Fuller understanding of variability in yield and production of wheat is of importance to students of the world wheat market, to students of fluctuations in agricultural production as a whole, and to students of general economic fluctuations or business cycles. Our study of this subject is designed for all three groups, but especially for the second and third. Its conclusions are not without interest for farmers, who most acutely feel the impact of individual, regional, and total variations in yield and output; and they are especially germane to proposals for planned regulation or "control" of agricultural production and exports.

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Five reasons for choosing wheat for such a study deserve mention. First, wheat is the world's largest crop, most notably in one particular: it occupies an area about double that devoted to maize or rice, the occupiers of land next in importance.

Second, fluctuations in the production of wheat significantly affect the volume and distribution of world trade. Trade in wheat and flour is of major importance both in quantity and in value, far exceeding that in corn and rice, the cereals of next importance in international trade.

Third, wheat is in considerable degree representative of other important crops, especially the small grains characteristic of the agriculture of the Temperate Zone. Winter wheat reflects conditions under which rye, winter barley, and other winter grains are grown. Spring wheat is indicative of most of the spring grains. Its representativeness for corn or rice is more limited, since their climatic and other requirements, their growing periods, and the technique of their cultivation are quite different from those of winter or spring wheat.

Fourth, the wide geographic spread of wheat is perhaps the most important reason why wheat is well suited for a study of variability of yield and production with a view to reaching conclusions that may serve as a basis for generalization with respect to other crops. Whereas corn and rice are more or less localized in specific climatic regions, wheat is cultivated under the most varied climates, though the bulk of the acreage is concentrated in moderately moist and drier regions. Short-term fluctuations in yields depend so much on various combinations of climatic factors that the study of yields produces conclusive results only when regional yields can be analyzed under varied climatic conditions. For this, wheat offers the widest possibilities.

Finally, the variability of yield and production of wheat was selected for intensive study because data necessary for such analysis have been accumulated in quantity and in convenient form in the Food Research Institute. It was therefore economical, and seemed highly appropriate, to undertake intensive analysis with respect to wheat before extending the research to other crops.

In Part I of the study, here presented, variability in wheat yields and outputs is considered in its time-sequence aspect, and regional data are analyzed as one type of economic time series. From analysis of sequences, of high, indifferent, and low yields, or of small, medium, and large crops, answers are sought to such questions as these: Are the fluctuations in wheat yield and production periodic, cyclical, or random in character? Are regional series of yield and production similar in this respect for various regions, or are there significant differences among regions?

I. VARIATIONS IN CROPS AND WEATHER

Annual data on yield and total production of wheat, or other crops, extending over a period of years, must be regarded as a special kind of time series, with distinctive characteristics as well as characteristics common to all kinds of time series. Crop statistics have especially close relationship to annual meteorological data and economic production series.[1]

Of the series used in our analysis, those on yields per acre have more characteristics in common with meteorological series, while those on total production have more in common with economic production series. This is because fluctuations in yields per acre are dominated mainly by variations of weather, while changes in total outputs are affected also to a considerable extent by variations in crop areas; and crop areas are influenced in some degree by two factors important in all kinds of economic production series—market considerations and growth of population.

This distinction between the two kinds of series used in this study is, to a certain extent, arbitrary. It is one of degree rather than of substance, since both are influenced by meteorological and economic factors, among many others, though in different proportion. The dominant influence of the weather factor on variation in yields is clearer for short-term fluctuations than for trends up or down, because the influence of economic factors on trends is quite evident. In dealing with variability in yield and production of wheat, however, we must concentrate attention on these short-term fluctuations in yields.

Types of Variations in Time Series

During the last two or three decades, it has been more or less established practice (though it has recently become less common) to analyze economic time series in several component parts, such as: (*a*) trend or secular trend, (*b*) cycles, and (*c*) residual or random fluctuations.[2]

The definitions of such components have never had a great degree of theoretical sharpness, since the practice of analysis of time series in their component parts, and the procedures adapted in analysis, have been largely empirical. The secular trend, in the meaning of a statistical description of a time series, has often been defined as the "gradual and persistent movement of the series over a period of time which, contrasted with the short run fluctuations of the series, is long."[3] This definition of trend may be regarded as adequate for a general understanding of time series. Its relativity is evident.

A cycle, or cyclical fluctuation, is usually understood as one of the types of short-term (relative to the total duration of the series) fluctuations, being more or less regular in its recurrence and having a wave-like appearance. Recurrence of rises and declines rather than strict periodicity is usually regarded as characteristic of cycles.[4] Strictly periodic

[1] We apply here the classification of economic time series used by H. T. Davis in *The Analysis of Economic Time Series* (Cowles Commission for Research in Economics, Monograph 6, Bloomington, Ind., 1941), pp. 7–9. Among several classes of economic time series, he emphasizes two as the most important: (1) price series and (2) production series.

[2] A fourth is usually added: seasonal variations. This may be regarded as a special kind of cycle, a 12-month seasonal cycle. In so far as crop statistics are given in annual values, we are not here concerned with this component of time series.

[3] Edwin Frickey, "The Problem of Secular Trend," *Review of Economic Statistics*, Oct. 15, 1934, XVI, 199.

[4] In "A Conference on Cycles," called in 1922 by the President of the Carnegie Institution, in which representatives of several sciences discussed the cyclical phenomena with which they deal, F. E. Clements gave a definition of cycle, which commended itself to the other members of the conference, in the following words: "In general scientific use . . . . the word (cycle) denotes a recurrence of different phases of plus and minus departures, which are often susceptible of exact measurement. It has no necessary relation to a definite time interval, though this is frequently a characteristic of astronomical cycles . . . . The significance of the term resides in the fact of recurrence rather than in that of the time interval, ... it seems desirable to use cycle as the inclusive term for all recurrences that lend themselves to measurement, and period or periodicity for those with a definite time interval, recognizing, however, that there is no fixed line between the two." ("Report of a Conference on Cycles," *Geographical Review*, Special Supplement, October 1923, XIII, 657–58. Quoted from W. C. Mitchell, *Business Cycles, Vol. I. The Problem and Its Setting*, National Bureau of Economic Research, New York, 1927, p. 377.) Harold T. Davis (*op. cit.*, p. 25) defined cycles as "the more or less regular variations about established trends." Davis is in agreement with Clements in that he does not assume strict periodicity in cycles, but he defines cycles in closer relation to trends.

cycles are usually called periods or periodicities.

Residual, irregular, or (as sometimes called) random components of a time series may be regarded as fluctuations of a still shorter run than cycles. But here definition is more difficult. The word "residual" indicates that all those fluctuations of a time series that are not accounted for by trend and cycles (including seasonal) belong to this group; the word "irregular" suggests that they are still less regular than cycles; the word "random" indicates that these variations are supposed to have characteristics of chance variables.[5]

The presence of all these components is not always evident in all economic time series, still less in all kinds of time series. For instance, it is usually difficult to ascertain the presence of secular trends in meteorological data such as annual averages of rainfall, temperature, or pressure. On the other hand, some kind of secular trend is usually characteristic of all economic production series. To Harold T. Davis, trend is "the most plausible structure" of economic time series, while in the opinion of Carl Snyder secular trend appears even as the dominating characteristic of most economic time series.[6] In this respect, series on total crop production also show greater similarity to other economic production series than do series on yield per acre. Secular trends are much more pronounced, or steeper, in the former than in the latter, though they are sufficiently evident also in most series on yield per acre, as may be seen from Chart 1 (p. 299).

The same chart shows not only that trends in yield of wheat for some regions are of substantial importance, but also that they vary greatly from region to region. It was the principal purpose of Bennett's study of trends in wheat yields to ascertain various kinds of trends in the principal wheat regions and to explain their courses on the basis of numerous and complex influences affecting them.[7]

Cyclical fluctuations also are not easily ascertainable in many meteorological data, particularly those given on an annual basis. Their presence in meteorological data is perhaps less evident than in most economic time series. The search for "cycles" or "periodicities" in meteorological data has long persisted, and there are still many meteorologists who have not abandoned hope of discovering "hidden cycles" or "hidden periodicities" in meteorological phenomena. But the opinion of a majority of conservative meteorologists has more and more crystallized around the idea that, even if periodic components in meteorological phenomena are real, their importance, measured in the magnitude of their amplitudes, is so small in comparison to random fluctuations that it cannot have much practical importance. For instance, it can hardly be used advantageously in weather forecasting.

This conclusion relates particularly to strictly periodic cycles or periodicities. The presence in meteorological phenomena of oscillations or of cycles of varying length and

[5] One of the principal achievements of the "variate difference" method of analysis of time series is to segregate random components of a time series from other components so that their characteristics can be studied and they themselves be measured. This represents a considerable step forward in the analysis of time series, for statisticians previously, according to Mitchell (*op. cit.*, p. 24), took irregular fluctuations for granted without attempting to define them as they define other components. For the most extensive exposition of the variate difference method by one of its originators, see Oskar Anderson, *Die Korrelationsrechung in der Konjunkturforschung* (*Veröffentlichungen der Frankfurter Gesellschaft für Konjunkturforschung*, Heft 4, Bonn, 1929). Recently Gerhard Tintner gave a comprehensive explanation of the method and of its applications for American readers in *The Variate Difference Method* (Cowles Commission for Research in Economics, Monograph 5, Bloomington, Ind., 1940).

[6] See Davis, *op. cit.*, pp. 15, 25, 208–09; Carl Snyder, "The Concept of Momentum and Inertia in Economics," in *Stabilization of Employment*, ed. by C. F. Roos (Bloomington, Ind., 1933), pp. 76–77.

[7] M. K. Bennett ("Trends of Yield in Major Wheat Regions since 1885," WHEAT STUDIES, October 1937 and March 1938, XIV, 69–102, 223–61) classifies various kinds of trends in yield of wheat in the following four groups: rising, irregular, stable, and declining trends. Because his purpose was first to ascertain various kinds of trend in yield and then to approach the problem of their causation, he selected for his purpose a moving average as the type of trend that is the least strict and rigid and that does least violence to the data. More specifically, he fitted to all regional (and subregional) series of yields a 9-year moving (weighted) average which is a resultant of two consecutive averages by 7 and by 3 items (p. 71). We have used the same trends in our study of short-term variability in yield and production of wheat. For general discussion of influences affecting trends in yield of wheat, see "Trends of Yield," pp. 76–87.

intensity, similar to those in economic time series, is more generally recognized, but to many meteorologists these "cycles" appear so irregular that their result can hardly be distinguished from chance.

Fluctuations in Meteorological Phenomena

In view of the fact that short-term fluctuations in yield, analysis of which is the principal object of this study, are apparently dominated by weather variations,[8] it is pertinent to cite a few authorities on meteorology concerning the character of fluctuations of meteorological phenomena, particularly in relation to the problem of periodicities in these fluctuations.

Of special interest in this connection are the conclusions of Professor Brunt, presented in a paper read at the 1937 meeting of the Royal Geographic Society.[9] He is an authority not only on meteorology but also on statistical methodology, and he has performed the most complete periodogram analysis of many meteorological series.

Reporting on his analysis of twelve meteorological records extending over long periods of years (these included the temperature at six European places, the rainfall at four, and the pressure at two),[10] Brunt says: "In not one of the twelve sets of records were the amplitudes of the periods found so great that it was possible to say that they might not have arisen as the result of a chance distribution of the observations."[11] After comparing some earlier results of similar analysis with the twelve records mentioned, Brunt further generalizes his conclusions thus: "we are forced to the conclusion that there are few periods, if any, which have such large amplitudes as to inspire confidence in their reality"; and he adds that "it is not possible to accept the cycles found in the earlier records as a true indication of what the future will bring."[12]

Then, leaving the problem of the reality of various periods in the meteorological phenomena that he studied, Brunt turns his attention to the practical importance of these periodicities; and he concludes that, in relation to both temperature and rainfall, the periods which appear in the periodograms with relatively large amplitudes account for only a very small fraction of the total variability of the actual phenomena observed. Thus by far the greater portion of the variability in temperature and rainfall must be accounted for by such fluctuations, the accidental character of which nobody questions.[13] His summary conclusion is this:

> It is shown that none of the cycles found occur with such great amplitudes that we can assert that they might not be due to a chance distribution of the observations, and not to truly periodic variations. It is shown that even if some of the cycles found are real physical cycles, they can only account for a small part of the variability of the meteorological phenomena; so small a part indeed that it is of little importance whether the so-called cycles are real or not.[14]

Sir Gilbert Walker, himself a pioneer in the development of long-range weather forecast-

[8] In the opinion of correspondents reporting on crop conditions in this country, 70 per cent of the total estimated reduction from full yield per acre of wheat was, on the average for 1915–24, due to adverse weather conditions. Among nonclimatic causes, plant diseases and insect pests were responsible for an additional 25 per cent of the total estimated reduction. But these latter factors, although nonclimatic in character, themselves depend to a considerable extent on weather. Adverse weather conditions were considered responsible for the reduction from full yield per acre of oats and corn (on the average for the same period 1915–1924) in still greater proportion (on 80 per cent or more). See the table entitled "Percentage Reduction from Full Yield per Acre of 8 Crops from Stated Causes, 1909–1924," published in *Crops and Markets, Monthly Supplement* (U.S. Dept. Agr.), January 1926, III, 11–12.

[9] D. Brunt, "Climatic Cycles," *Geographic Journal*, March 1937, LXXXIX, 214–30.

[10] Data on temperatures of London, Edinburgh, Paris, Berlin, Vienna, and Stockholm were analyzed; the rainfall of Milan, Padua, Edinburgh, and London; and the pressure of Edinburgh and Paris.

[11] *Op. cit.*, p. 221.

[12] *Ibid.*, p. 222.

[13] It must be mentioned here that in no single set of the twelve series studied could Brunt find a strongly marked cycle of 35 years, the so-called Brückner's cycle, the existence of which was claimed by Brückner on the basis of his analysis of European meteorological data. Nor could he find in any of his four rainfall series the periods of 5.7, 11, 14, and 21 years, evidences of which were claimed by Professor A. S. Douglas from his study of the tree-ring records in the West of this country. Only one of the twelve periodograms, that relating to Edinburgh temperature, showed an appreciable indication of the period of 11 years, roughly corresponding to the sun-spot cycle, the duration of which varies within wide limits.

[14] *Op. cit.*, p. 230.

ing, responsible for several forecasting formulas of rainfall (for British India, and North Australia) and of temperature (for North America), said in discussing Professor Brunt's paper: "I do not know a single period, other than those of sunspots, of which the reality is clearly established by the necessary use of the mathematical criteria."[15]

Most of the very numerous periodicities in meteorological phenomena, evidence of which have been claimed by many meteorologists, have not been established "by the necessary use of mathematical criteria." It is still true, as Normand wrote a decade ago, that unfortunately only a few authors studying meteorological periodicities have submitted their work to critical tests by comparing their results with those expected from pure chance; and still fewer have compared the curve obtainable from their selected periodicities with the original curve or have expressed in any standard statistical form the goodness of the period as a forecasting factor.[16] The problem of such tests of significance is complicated by the lack of agreement on the criteria of reality of periodicity. Indeed, Page said recently that "no method of determining the existence and significance of periodicities is universally accepted."[17]

Finally we may quote from a recent elementary text written by a senior meteorologist of the United States Weather Bureau, which is responsible not only for collection but also for thorough analysis of American meteorological data. Speaking of fluctuations of various weather elements, such as rainfall, temperature, etc., Blair says:

> There can be no doubt of the existence of the fluctuations, but none is truly periodic in its recurrence. Much attention has been given to the statistical analysis of weather data in the hope of finding periodicities that would be useful as indicators of future conditions, and a great many so-called cycles have been found in this way. There is a list of more than 100 of these, varying in length from 8 months to 260 years, but they all show irregularities: successive recurrences are of different length and intensity; the cycles are interrupted by departures in the opposite direction; after persisting for several periods, a cycle may suddenly fail, sometimes to begin again later in a different phase. There are so many of these "cycles," and they are so irregular, that the result can hardly be distinguished from chance. They have not proven of practical value in forecasting next year's weather.[18]

In short, leading meteorologists have become skeptical both concerning the real existence of strictly periodic cycles in meteorological data and concerning their importance in the analysis of such data. For our purpose, the latter point is the more important, since even a real periodicity in meteorological phenomena is of small importance in analysis of crop fluctuations, if it accounts for only a very minor portion of the total variability in weather elements.

However, even complete rejection of the idea of strictly periodic cycles in meteorological data does not imply that their apparently irregular fluctuations are to be regarded as purely accidental and fortuitous. A certain degree of interconnection may exist between meteorological values in consecutive time-units, such as the day, week, month, or (perhaps) year. Consequently, fluctuations in such weather elements as rainfall or temperature from one time-period to the following, and their deviations from long-term average or normal, may not be random in character.

If variability must be regarded as one characteristic of weather, a certain degree of persistence is another characteristic. Persistence of weather conditions during relatively short periods of time, for several days or several weeks, is more or less generally recognized by meteorologists, and their reality has also been demonstrated statistically. As Blair says:

[15] *Ibid.*, p. 233. Sir Gilbert evidently means periods in meteorological phenomena. He modified the criterion offered by Sir Arthur Schuster for testing the reality of a period revealed by harmonic analysis. We cannot resist adding here the continuation of Sir Gilbert's statement to the effect that "some of the period-finders seem to recognize this, for one at least has said that he has ceased to pay attention to criteria because when he did so he obtained scarcely any results of interest."

[16] C. W. B. Normand, "Present Position of Seasonal Weather Forecasting," *Quarterly Journal of Royal Meteorological Society*, 1932, LVIII, 3–10.

[17] L. F. Page, in his "Introduction" to the recently published *Reports on Critical Studies of Methods of Long-Range Weather Forecasting* (*Monthly Weather Review*, Supplement 39, 1940), p. iv.

[18] T. A. Blair, *Weather Elements, A Text of Elementary Meteorology* (New York, 1940), p. 303.

It is evident at once, ... that we do not experience our weather entirely by a random sampling of the possible combinations of the weather elements. . . . . It is also clear that the different meteorological elements do not vary with complete independence.[19]

After citing several illustrations of weather spells, he concludes: "These are illustrations of the fact that today's weather is not independent of yesterday's."[20]

This persistence in weather elements is even now regarded as one of the principal bases for a scientific long-range weather forecasting.[21] However, even those who emphasize this characteristic of weather recognize the smallness of the degree of persistency, particularly in Temperate Zones of the Northern Hemisphere, and its relatively short duration.[22] Even in those regions in which persistence of weather characteristics from one season to the next was found to be the strongest—as in the area of the South Pacific and Indian oceans, the region of the so-called "southern oscillation," so much studied by Sir Gilbert Walker—significant relationships for various weather elements such as pressure, temperature, and rainfall were established only between quarterly average values within a year, while the correlations established between quarterly average weather characteristics for consecutive years were hardly significant.[23]

Hence the indication is that persistence in various weather elements continues for relatively short periods, usually not exceeding several months. For these reasons, it is natural to expect that fluctuations in monthly average rainfall or temperature from one year to another, or fluctuations in the annual average for the same weather characteristics, may be regarded as independent random fluctuations, rather than interrelated fluctuations, especially when the region concerned is in the Temperate Zone important in wheat production. Although considerable diversity of opinion on this subject exists, it is presumed that changes in rainfall, temperature, and other weather characteristics from year to year are of random character.[24] This conclusion is of importance for the analysis of variability in yields of wheat, because annual variations in yields depend mainly on variations of seasonal weather from one year to another. Furthermore, by far the greater portion of wheat acreage is in the Temperate Zone, where persistence in weather elements is particularly small.

Several conclusions may be drawn from the above characteristics of weather fluctuations, which may be of some guidance in the analysis of crop statistics, particularly of yield series.

[19] *Op. cit.*, p. 256.

[20] *Ibid.*, p. 260. For various illustrations of persistence in weather see also Julius von Hann, *Lehrbuch der Meteorologie*, edited by Reinhard Süring (Leipzig, 1926), pp. 632–41. This subject is also discussed from the point of view of statistical theory in an article by H. W. Clough, "A Statistical Comparison of Meteorological Data with Data of Random Occurrence," *Monthly Weather Review*, March 1921, XLIX, 124–32.

[21] For the point of view of Sir Gilbert Walker on this subject, see his presidential address, "Seasonal Weather and Its Prediction," before the British Association of Advancement of Science, 1933, reprinted in the *Annual Report of the Smithsonian Institution* (Washington, 1935), pp. 117–38, especially pp. 118–19.

[22] *Ibid.*, pp. 122, 132.

[23] Details on this subject may be found in the several *Memoirs* of Sir Gilbert Walker on "World Weather," particularly *World Weather V* and *World Weather VI*, published in *Memoirs of the Royal Meteorological Society* (1932), IV, 53–84; and (1937), IV, 119–39. See also R. B. Montgomery, "Report on the Work of G. T. Walker," *Monthly Weather Review*, Supplement 39, 1940, pp. 1–22. The application of the test (explained later on pp. 297–99) for randomness of sequence in the variations of the numerical definition of the "southern oscillation," as it is given in "World Weather V," shows that these variations from year to year conform satisfactorily to the hypothesis of randomness.

[24] Here may be mentioned a few publications that deal with the problems of interdependence between meteorological phenomena in successive periods and that substantiate the above conclusions to a certain extent: W. T. Russell, in "The Relationship between Rainfall and Temperature as Shown by Correlation Coefficients" (*Quarterly Journal of the Royal Meteorological Society*, July 1922, XLVIII, 225–30), presents results of an analysis of monthly mean temperature and monthly rainfall for four places in Great Britain, covering periods of 34 to 65 years. The correlation coefficients between the same months in successive years were found to be practically insignificant. J. W. Hopkins, in "Agricultural Meteorology: Some Characteristics of Precipitations in Saskatchewan and Alberta" (*Canadian Journal of Research*, September 1936, Vol. XIV, Sec. C., pp. 319–46), says that correlation studies revealed no consistent association between the amount of precipitation in different spring and summer months of the same year, or between the totals for the autumn and winter, and for the following spring and summer period; and he adds: "In the long run the amounts of precipitation in the five summer months [April–August] seem to have fluctuated independently from year to year" (p. 327).

1. The search for periodicities in fluctuations of yields can hardly be more promising than that in relation to meteorological phenomena. In our opinion, indeed, it must be less promising. The number of independent factors determining variation in yields is still greater than those affecting weather fluctuations, and their relationships are still more complex. Periodic fluctuations in weather conditions, if they exist, account for only a small portion of the total variability of crops; and factors other than weather elements, such as soils, plant diseases, insect pests, and many other biological factors connected with the growth of plants, are of importance. The influences of weather elements on yields depend not only on variations in any one of these elements separately, but also on their coincidence in time among themselves as well as with certain stages in the growth of plant.[25] Under such circumstances, much more place is left for chance than for regularity in fluctuations in yields. If we add to this the fact that series of reliable statistics for crops are more scanty and of shorter duration than those for meteorological data, it becomes clear that we have very little chance of proving the reality of periods in crop fluctuations even if they exist. Consequently, no search for periodicities in fluctuations of wheat yields seemed advisable.

2. The fortuitous components in the variation of weather elements from one year to another are of such great importance that they must affect fluctuations in yields to a considerable extent. This suggests that the hypothesis of random character of fluctuations in yields must be tested first.

II. TEST FOR RANDOMNESS OF FLUCTUATION IN YIELDS AND OUTPUTS

Testing of time series for randomness of their sequences is a relatively new development in statistical methodology. Modern statistical theory was developed without particular regard to special problems of time series, and most of the tests of significance disregard temporal characteristics or sequence of variations in time series.

Several meteorologists, however, have approached the problem of comparing meteorological data with data of random occurrence, and have even established certain mathematical criteria which may indicate that data under consideration follow a pattern peculiar to random occurrences, on certain assumptions. But none of them has proposed a practical method for testing whether observed data are sufficiently close to those expected theoretically on the assumption of randomness of occurrence, or significantly different from them to indicate that observed data do not behave as random occurrences.[26] However, such a test is of primary importance, since observed data are never in exact numerical agreement with those expected theoretically, and their conformity to a theoretical pattern must always be tested.

Such a test has been recently developed by

[25] The complexity of factors affecting yields is well analyzed by the late C. L. Alsberg in his study, "Forecasting Wheat Yields from the Weather," WHEAT STUDIES, November 1928, V, 1–44, especially Sec. III, "Plant Reactions to Weather Factors," pp. 11–20.

[26] Two names deserve special mention in this connection. (1) Charles Goutereau introduced a measure now called the "Goutereau constant," which is useful in testing the randomness of series ("Sur la variabilité de la température," *Annuaire de la Société Météorologique de France*, 1906, LIV, 122–27, summarized by E. W. Woolard in *Monthly Weather Review*, March 1921, XLIX, 132–33). The Goutereau constant is the ratio of the mean variability to the mean deviation. This ratio is equal to $\sqrt{2}$ for a set of normally distributed values arranged in random sequence, and to 4/3 for a set of equally probable values arranged in random sequence. For mathematical proof, see Davis, *op. cit.*, pp. 144–49, where the standard error of the Goutereau constant, proposed by Davis with reference to Herbert E. Jones of the Cowles Commission, is also given. With the standard error determined, the Goutereau constant may be used now for test of significance of time series for randomness of sequences in their variations. (2) Louis Besson has developed a formula for determining theoretical frequency of various duration intervals between consecutive minima in a series of normally distributed values or of equally probable values arranged in random sequence ("On the Comparison of Meteorological Data with Results of Chance," translated and abridged by E. W. Woolard, *Monthly Weather Review*, February 1920, XLVIII, 89–94). But he did not discuss the problem of determining whether differences between observed and expected frequency are significant. This problem was later solved by other scientists.

W. Allen Wallis and Geoffrey H. Moore, while associates of the National Bureau of Economic Research. They developed their test for the special purpose of testing the hypothesis that variation in crop production is dominated by random factors—the same hypothesis that we are testing here in respect to yield and production of wheat. Here we cannot go far in a technical explanation of the procedure of the test,[27] but the principles, which are relatively simple, may be presented.

The principal advantage of the proposed test is that it makes no assumptions regarding the character of the frequency distribution of the data of which the time series is considered to be a sample. For instance, in applying the test to yield data, we do not need to work on the assumption that variations in yield follow the normal distribution (i.e., that small deviations from an average yield are frequent, larger deviations are less frequent, crop failures or bumper crops are rare, and that all these are symmetrically distributed around their average); or, on another assumption, that all deviations from the average yield—small or large, above or below average—are equally probable. Variations in yield may follow various patterns in different regions, and conclusions regarding randomness in the variation of yield would be insecure if based on a test requiring some one assumption regarding the frequency distribution of yield variations.

The Wallis-Moore test is based on sequence in direction of movement up and down, and disregards the magnitude of year-to-year fluctuations, treating the smallest as equivalent to the largest. Thus it does not utilize all of the information in the data; but by this sacrifice, the test achieves greater generality.

Each point at which the series under analysis ceases to decline and starts to rise, or ceases to rise and starts to decline, is called "a turning point." A turning point is a "peak" if it is a maximum or a "trough" if it is a minimum. The interval between consecutive turning points is called a "phase." A phase is an "expansion" or a "contraction" according to whether it starts from a trough and ends at a peak, or starts from a peak and ends at a trough. The length or duration of a phase is the number of years between its initial and terminal turning points.[28]

In terms of these definitions, the authors develop mathematical formulas that enable them to compute for a series of any number of independent random observations the expected frequency distribution of phase durations, as well as the mean duration of phases. In applying the test, frequencies of 1-year, 2-year, and longer than 2-year phases must be computed.

The theoretical frequency distribution of phase durations for a random series of a given duration serves as a standard; and with this are compared empirical frequency distributions of phase durations, obtained from observed time series of the same duration by counting phases of various lengths according to the established definitions.

The principal achievement of the authors is that, in addition to these theoretical frequency distributions of phase durations in random series, they developed also a special test of goodness-of-fit of observed frequency distributions to theoretical. In this test, the observed and expected frequencies are compared in the usual way for testing goodness-of-fit; but the test itself is not quite identical with the usual test of goodness-of-fit.[29]

The authors of the test explicitly recognize that their test is lacking in sensitivity to pri-

[27] Such explanation, illustrated by application of the test to empirical data, is given in W. A. Wallis and G. H. Moore, *A Significance Test for Time Series and Other Ordered Observations* (National Bureau of Economic Research, Technical Paper 1, New York, September 1941) [hereafter referred to as *Technical Paper*]. For a short presentation of the principles, see, by the same authors, "A Significance Test for Time Series Analysis," *Journal of the American Statistical Association*, September 1941, XXXVI, 401–09.

[28] Wallis and Moore, "A Significance Test for Time Series Analysis," p. 401.

[29] In the Wallis-Moore test, the differences between actual frequencies of phases of 1-year, 2-year, and longer than 2-year durations and corresponding theoretical frequencies are squared and divided by the respective theoretical frequencies. The authors call the sum of resulting ratios χ^2_p. But the distribution of χ^2_p does not quite conform to the Pearsonian distribution function of χ^2. They secured empirically (from 700 random series) the sampling distribution of χ^2_p and compared it with the Pearsonian distribution function χ^2. From this comparison, they determined how χ^2_p must be adjusted in order that usual χ^2 tables could be used in the test.

mary trend; that is, it does not easily reveal the presence of such trend in a series. A time series with quite visible trend, like some of the series on yield of wheat per acre presented in Chart 1, would be classed as a time series with random sequence in variation, in spite of the visible trend. This lack of sensitivity to trend, though a limitation of the technique, makes it possible to apply the test to original series without preliminary elimination of trends. This has the advantage of making the test simple and economical to apply. Furthermore, there has been a tendency recently to preserve trends in time series even when the problem of their cyclical fluctuations is being studied.

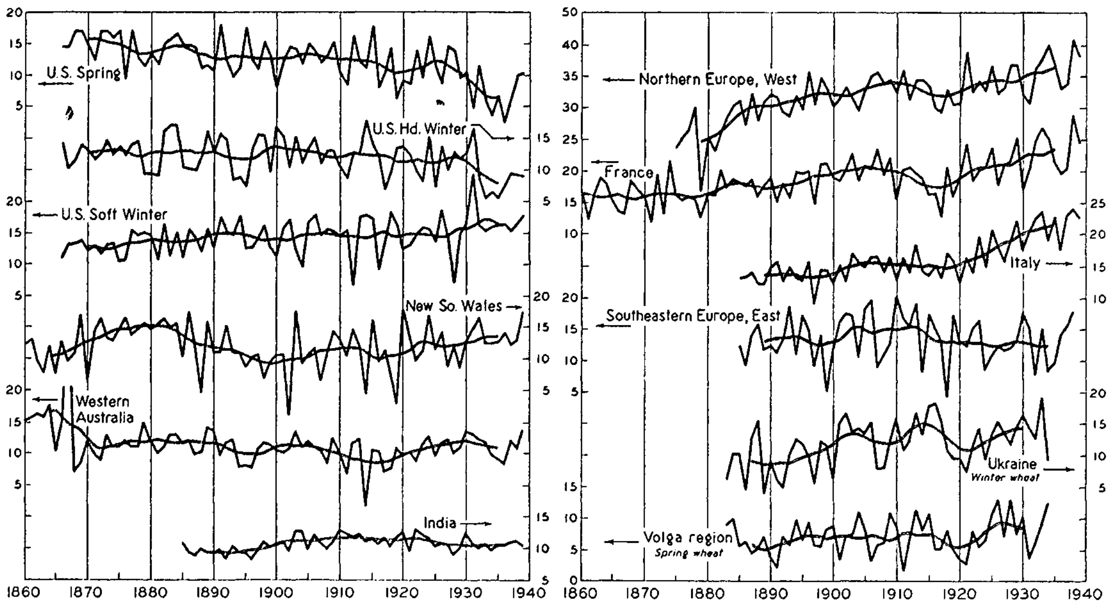
In our particular case, trends in yields of wheat were determined in the form of 9-year moving averages (weighted), and they were subjected to preliminary study (see pp. 292–93). But it was found advisable to apply the test for randomness in fluctuations of yield directly to the original series and not to their deviations from the respective trends.

The Wallis-Moore test is also not very sensitive to certain kinds of cyclical fluctuations, particularly those smooth in character and with annual cyclical changes definitely smaller than year-to-year random changes. This statement may be substantiated by findings of the authors themselves. When they applied their test to various crops in America and Europe, they found that fluctuations not only in yields but also in the total outputs behaved like "random" series, while the fluctuation in acreage was not random.[30] Particular series on acreage of sweet potatoes in the United States, used for the demonstration of applications of the test in the *Technical Paper*,[31] show cyclical fluctuations quite clearly. The series on total production of sweet potatoes, being a product of acreage by yield per acre, includes these cyclical fluctuations in acreage; yet their presence is not revealed by the test. The fact that the Wallis-Moore test disregards the magnitude of year-to-year fluctuations, treating the smallest as equivalent to the largest, while increasing the generality of the test, may make it less conclusive.

It must be added here that, when the test is applied to crop statistics, the fact that it gives the same weight to small fluctuations

CHART 1.—ANNUAL YIELDS OF WHEAT PER ACRE, WITH TRENDS, FOR SELECTED REGIONS*

(*Bushels per acre*)



* Sources of data indicated in Appendix Note.

[30] National Bureau of Economic Research, *Twenty-first Annual Report of the Director of Research* (New York, 1941), pp. 8–9.

[31] Chart, p. 37.

as to large ones increases the chance of indicating randomness of variations in crop estimates, rather than of real variations in yield. Indeed, it is reasonable to assume that large fluctuations in yield estimates will usually reflect variations in "real" yields, while many small fluctuations may simply reflect errors in crop estimates, which presumably are random or at least include a random component in addition to a systematic bias.

Thus the conclusion from the test that variations in a given time series, particularly in a series on crop yields or production, are in agreement with the hypothesis of randomness in the sequence of variations does not mean that the possibility of existence of some kind of interdependence between consecutive items of a series is completely excluded. It demonstrates, however, that possible cyclical changes in a series, when they are measured between consecutive years, are definitely smaller than year-to-year fluctuations in the same series, and consequently that such cycles must be only of no more than secondary economic importance when compared with larger fortuitous fluctuations.

Data Used in the Test

As we have seen, variations of weather elements such as rainfall or temperature may have different characteristics in various regions. In some areas, weather may have greater persistence—as in certain tropical regions (see p. 296); in others it may be more variable—as in the Temperate Zone. Furthermore, crop fluctuations in some regions may depend more on one weather characteristic, and in others on another. Variation in rainfall is a major factor determining fluctuations in yield in semiarid regions where moisture is at a minimum; but in moderately moist regions variation in temperature or some other weather element may be of relatively greater importance. Hence the hypothesis of randomness of fluctuation in yields must be tested under various climatic environments. Wheat provides favorable conditions for such a test, since it is cultivated under a great variety of climatic conditions.

In our selection of regions for study of variability in wheat yields, we have followed with minor variations the scheme of regional subdivisions employed by Bennett in his "Trends of Yield in Major Wheat Regions since 1885."[32] To quote him:

> The attempt was made to define wheat regions in such a way that each region would be fairly homogeneous with regard especially to type of wheat grown, climate, place of wheat in agriculture, magnitude of acreage, and direction of trend of wheat acreage.

Following these principles, he divided the wheat "world" (excluding Russia, China, and several other less important areas) into 14 major regions and a total of 40 smaller subregions. North America is divided into 6 regions with 17 subregions, Europe into 5 regions with 14 subregions; Australia, South America, and India were taken as separate regions, each subdivided into 3 subregions. Although none of the 14 major regions is truly homogeneous according to Bennett's criteria (as the author explicitly recognized), each subregion is much more nearly homogeneous.

Regions and subregions so established appear satisfactory for the purpose of a study of variability in yields. Since the purpose of this study is to present a world-wide picture of the variability in wheat yields, it was unnecessary to go into more detailed subdivision. Further subdivision was in many cases precluded, because many European frontiers were shifted by the war of 1914–18, and it was possible to preserve approximately the same frontiers for the entire period here under study only for relatively large regions. Preservation of the regions used in the study of trends in yields was imperative also for the reasons that trends in yields present one of the types of variability, and study of short-term fluctuations in yields presupposes preliminary study of trends. Thus, in the present study of short-term fluctuations in yield, it was economical to rely on the previous study of trends in yields.

In some minor points, mostly mentioned below, it was necessary to depart from the regional scheme used in the earlier study of trends. Detailed descriptions of regions, as well as of regional series on yields and pro-

[32] *Op. cit.* For description of regions, see pp. 71–73.

duction used in the test of randomness, are given in the Appendix Note and Table I.

The principal reason for these departures is that the crop statistics for some regions, or for their component parts, are much less satisfactory for the earlier portion of the period covered by the trends study (1885–1900) than for the same period in some other regions, or for all regions from 1900 on. Rough estimates of production and acreage made in several cases by Bennett[38] were satisfactory for his analysis of trends, but not for study of variability in yields. On the other hand, study of variability in yields with emphasis on sequence in variation requires use of long-time series. Under such circumstances, instead of using crop statistics for entire regions but for short periods only, it was imperative to take longer series even though they cover only portions of the respective regions. Such departures were necessary mainly in respect to European wheat regions. All major wheat regions in Europe, as established in the trends study, are represented in our analysis of sequence in variations of yield; but some of them are represented by series relating only to a smaller portion of the respective regions, for instance Southeastern Europe and the Western Mediterranean area.

In our analysis of variability in wheat yield, it was found advisable to include crop statistics for some of the wheat regions of European Russia, which have peculiar characteristics. Three such regions were included in this study: Ukraine, the North Caucasus, and the Volga region. In the first two of these regions, winter and spring wheat were taken separately; in the Volga region only spring wheat was included, since negligible quantities of winter wheat are grown in this area. These Russian regions are of relatively large size. Only in this way is it possible to preserve approximately the same frontiers for the prewar and postwar periods, since postwar crop statistics have been reported for administrative regions the frontiers of which have been frequently changed. Even in such wide frontiers, the identity of Russian regions can be preserved only very roughly, but some shifts in frontiers cannot significantly affect regional average yields per acre.

Length of duration of a series is of particular advantage in the analysis of the sequence of variations in yield. Hence in this analysis it was advisable to include series on yield for the entire period for which crop estimates for the respective regions are sufficiently reliable. Thus, here we use variable and frequently much longer periods, instead of a uniform period beginning with 1885. Practically all regional series for the United States were extended back to 1866, those for Australia to 1860, and several for western Europe to various dates earlier than 1885. Although uniform duration of a series is of advantage for some comparisons of variability of regional series, it was not imperative to use series of the same duration in our analysis of sequence of variation in yield.

In order not to make computation prohibitive, the plan was to apply the test for randomness of sequence to series relating to major regions. But in the case of several regions, series for subregions or even for smaller areas were used in the test. This practice was applied to the least homogeneous of the regions established in the trend study, for instance Eastern North America, the United States Hard Winter area, Australia, and Northern Europe. For the first three regions, subregional series were used; and for Europe, series for individual countries or groups of small countries. Some regions required closer attention, because study of their crop statistics indicated that they do not comply with the hypothesis of randomness of fluctuation. This was true of the United States Soft Winter area, for which, as in some other cases, two types of yield data were used—per acre harvested and per acre sown.

Results of the Test on Yield Fluctuations

The results of the test are summarized in Table I (see Appendix Tables for all numbered tables). For each of the 39 series tested, the table shows (*a*) the entire duration of the series, (*b*) the average duration of expansions

[38] All cases of such approximations and of bases on which they were made are indicated in the earlier study by M. K. Bennett, "World Wheat Crops, 1885–1932," Wheat Studies, April 1933, IX, 239–74, particularly pp. 240–45.

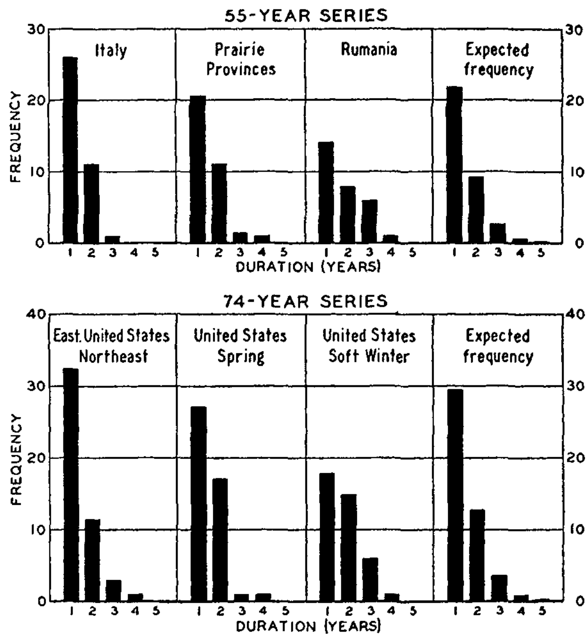
and contractions, (*c*) the average duration of both kinds of phases combined, and (*d*) the number of combined phases of various durations. Shown also for each series are probabilities, or rather limits within which they lie, indicating the degree of conformity of variations to the hypothesis of randomness of their sequences. In other words, they show how probable it is that empirical frequencies of various duration phases, counted between successive turning points of the respective series, are in conformity with theoretical frequencies for the respective phase durations, computed for a series of the same number of items taken at random.

Some frequency distributions of phase durations selected as representative of series with short, medium, and long average duration of phases, are shown in Chart 2. One set of distributions is taken from series of shorter total duration (55 years, the upper part of the chart), and another with longer (74 years, lower part). In each of the two sets, a theoretical distribution for random series of the same total duration is included for comparison.

In the frequency distribution representing Italian series, the occurrence of 1-year phase durations (that is, alternation of good and poor crops from one year to the next) is slightly more frequent than would be expected of chance variations (designated "expected frequency"), while the occurrence of 3-year and longer duration phases, taken together, is slightly smaller. To a certain degree, the same is true of data for the Eastern United States, Northeastern subregion. On the other hand, in the distribution for Rumania and the United States Soft Winter area, Eastern subregion, which have long average duration of phases, the frequency of 1-year phases is substantially smaller than expected in a random series, while the frequency of 3-year and longer phases is greater than theoretically expected. However, in all cases except Rumania, the deviations of observed frequencies from expected are not large enough to warrant the conclusion that they were not produced by chance. But even in the case of Rumania all that may be said on the basis of the probability given in the last column of Table I is that in no more than one case out of 20 could chance produce so many long phases.

Frequency distributions of phase durations for the Prairie Provinces and for the United States Spring Wheat area represent cases in which average duration of phases is medium, near to that expected theoretically from chance occurrences. But the frequencies of various duration even in these cases deviate substantially from those expected theoretically for

CHART 2.—FREQUENCY DISTRIBUTIONS OF PHASE DURATIONS IN FLUCTUATIONS IN WHEAT YIELDS PER ACRE FOR SELECTED REGIONS COMPARED WITH EXPECTED DISTRIBUTION FOR RANDOM SERIES*



* Data mainly in Table I.

chance occurrences. This is particularly true of the United States Spring Wheat area. Indeed, it may be seen from the chart that phases of 2-year duration occur more frequently, and that those of 1-year and of 3-year duration occur less frequently, than it would be expected of random occurrences. But these deviations also are not large enough to indicate that they could not be produced by chance.

Some of the regions for which frequency distributions of phase duration given in Chart 2 are represented also by curves in Chart 1 (p. 299). Scrutiny of these curves may lead to a better understanding of the frequency distributions just discussed.

Average duration of phases.—In order to facilitate further analysis of the average durations of expansions and contractions in the fluctuation of wheat yields, we summarize in the accompanying table data given in Table I for each regional series separately. Series are grouped here by large geographical areas.

It may be noted first that the average duration of expansions is somewhat longer than that of contractions in the combined averages for all series used in the test. This is particularly so in the averages for 12 series relating to Europe ex-Russia (including Algeria) and for 15 series relating to North America. But the relationship is reversed in the case of averages for Australian and Russian series. The explanation is found in the divergent proportions of series with various trends. In series with definitely rising trends in yield, the average duration of expansions tends to be longer than that of contractions. The opposite tendency is characteristic of series with declining trends. Of the 39 series used in the test, trends of 19 are definitely rising and those of 5 definitely declining, while the remaining 15 trends are stable or irregular (during one part of their duration they are rising, during another declining).[34] Practically all series with rising trends are in Europe ex-Russia or in North America. Of 12 series tested for Europe ex-Russia, 7 have definitely rising trends, while in 5 series trends are stable or irregular. In North America, 9 of the 15 series have rising trends, 5 declining, and 1 irregular. But none of the Australian series have definitely rising trends, all being irregular, while only 2 of the 5 Russian series have a slightly rising tendency.

MEAN AVERAGE DURATIONS OF PHASES IN FLUCTUATION OF WHEAT YIELDS PER ACRE, SUMMARIZED BY SELECTED GROUPS*

Area and number of series	Expansion	Contraction	Both combined	Combined adjusted for ties
North America (15)....	1.60	1.52	1.56	1.54
Europe ex-Russia (12)..	1.57	1.46	1.52	1.50
Australia (5)..........	1.55	1.62	1.58	1.58
Russia (5).............	1.64	1.66	1.65	1.63
"World" ex-Russia (34)	1.58	1.52	1.55	1.54
"World" (39)...........	1.59	1.53	1.56	1.55

* Data for individual series in Table I.

Such relationships between trends and relative duration of expansions and contractions, however, do not always find their expression in individual cases. In some instances, contractions are on the average longer than expansions, in spite of a definitely rising trend (e.g., Italy). A similar situation is characteristic of series with declining trends. Since the element of chance is present in these relationships,[35] it was decided to apply the test for randomness to all phases combined.

The average duration of combined phases for all 39 series, as well as for the subgroups of series, exceeds 1.5 years. The longest average duration of phases is characteristic of the group of Russian series, with the Australian second. The shortest is for the European series. It must be noted here that the average duration of all combined phases exceeds 1.5 years also in the case of phases adjusted for ties.[36] Theoretically, the average

[34] This classification is based partly on Bennett, "Trends of Yield," and partly on an analysis of similar trend lines fitted to series which were not included in that study. Diversity in these trends may be seen from Chart 1 (p. 299), where curves representing annual yields and their trends for a sample of regional series are given.

[35] Note that the longest average duration of expansions (2.00 years) occurs in Rumania and in one of the subregions of the United States Hard Winter area, where no rising trends appear.

[36] Two or more consecutive items in a yield series with the same values constitute a tie when it is not possible to ascertain whether the yield increases or decreases between successive years. One of the assumptions of the Wallis-Moore test is that the probability of two consecutive observations being identical is infinitesimal (see *Technical Paper*, p. 5). This assumption is formally correct in so far as at least a slight difference between yields in consecutive years would always exist. It would usually be possible to find this difference by extending the number of decimals in the quotient of the total production over acreage. But crop statistics on yield, given with one decimal according to our practice, from time to time produce identities in yields in consecutive years, or ties. In counting turning points in empirical series, we made it a rule not to count as a turning point such ties when the movement of a series after the tie continued in the same direction as before it, that is when the yield continued to rise farther or to decline farther. In ties which occur on a peak or on a trough, the last of consecutive equal items was regarded as a turning point. In order strictly to fulfill theoretical requirements of the Wallis-Moore test, it was necessary to treat these ties in accordance with the procedure de-

duration of phases in a random series with durations below 80 years, as are the series used in our tests, must be slightly below 1.50 years.[37] Thus a somewhat longer average duration of phases in series on yield used in the test points to some divergence of these series from random series; but, as will be shown, this divergence is insignificant.

Average durations of phases (adjusted for ties) in individual series deviate substantially from the theoretical duration for a random series. They are as long as 1.79 years (Rumania), 1.75 years (United States Soft Winter, Eastern subregion), 1.74 (North Caucasus, spring wheat), 1.70 years (United States Hard Winter, Northeastern subregion), 1.67 years (Ukraine, winter wheat; Australia, Victoria). But there are, on the other hand, average phases as short as 1.31 years (Germany), 1.32 (Southeastern Europe, West), 1.33 years (Hungary), 1.34 years (Italy), and 1.40 years (Eastern United States, Southeastern subregion). In all cases, there are substantial differences from the duration for a random series. In the first group, fluctuations approach "cycles" with average durations of 3 to 4 years; and for the other group, large and small yields tend to alternate from one year to the next. The question arises: Do not these differences correlate with some climatic characteristics of respective regions?

Scrutiny of data in Table I does not lead to the conclusion that there exists some systematic distribution of various types of fluctuations in yields by climatic regions. Average durations of phases in fluctuation of yields are long in some of the dry areas, such as several Australian regions, most of the Russian, Rumania, and the United States Hard Winter area. On the other hand, fluctuations in yields in the driest wheat region of Russia —the Volga—have only a moderate average duration of phase (1.52 years), while in the relatively dry United States Spring Wheat area the average duration of phases is also relatively short (1.47 years). In New South Wales, one of the driest wheat regions of Australia, fluctuations in yield have phases of relatively short durations (1.49 years), the same as in the driest, northwestern portion of the United States Hard Winter area (1.56 years). At the same time, average durations of phases are relatively long in such moist areas as the eastern portion of the United States Soft Winter area (1.75 years, for yield on harvested acreage), or the British Isles and the Low Countries (1.62 years). This is characteristic also of Argentina, where wheat is cultivated mostly in the moist area.

Nor are fluctuations with short average durations of phases characteristic of some particular climate. We find this type of fluctuation in regions with various climatic characteristics — Italy, Germany, Hungary, the Eastern United States. Thus it may be concluded that fluctuations of yields with relatively long or relatively short phases do not seem to be related to some climatic characteristic of regions.

Average durations of expansions and contractions vary in wider range than those for all phases combined together. This is to be expected, since average durations of all phases result from averaging by pairs of average durations of expansions and contractions.

Chart 3 presents separately the frequency distributions of average phase durations for expansions, contractions, and for all phases combined. The last are given both for phases as they were counted from series, and as adjusted for ties (see footnote 36). Class intervals for expansions and contractions are taken 1.5 times wider than for combined phases in view of the wider range of their variations. The chart shows that frequency distribution for means of expansions is more skewed than that for means of contractions. The modal class for expansions—1.60 to 1.75—is above the mean average for all 39 series. On the other hand, the frequency distribution of con-

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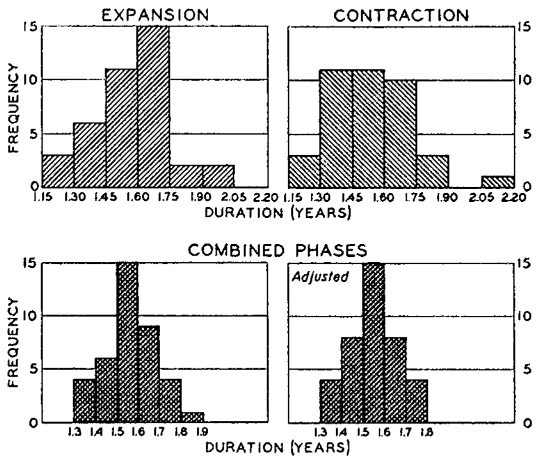
scribed on page 36 of the *Technical Paper.* Combined phases obtained in strict accordance to the Wallis-Moore procedure we here designate as "adjusted for ties." Table I shows that their average durations differ slightly from the average durations of combined phases obtained according to the procedure described above. The Wallis-Moore procedure of treating ties may result in fractional frequencies of various duration phases, as may be seen from the same table.

[37] At the limit, it would approach 1.50 units when the number of items in a series is infinitely large. For series from 55 to 80 items, as are a great majority of ours, the theoretical average duration is about 1.49 units.

traction durations is flat-topped. The frequency distributions of all phases combined are more regular in form; and, with the limits of class intervals appropriately selected,

CHART 3.—FREQUENCY DISTRIBUTIONS OF AVERAGE PHASE DURATIONS IN FLUCTUATIONS IN WHEAT YIELDS PER ACRE FOR 39 SELECTED SERIES*



* Data in Table I.

they are both quite symmetrical, particularly that for combined phases adjusted for ties.[38] Such regularity in distribution of average phase durations in a relatively small sample of 39 series, which are not particularly homogeneous (p. 301), points to accidental variations in the duration of phases in various regional series on yield.

Conclusions from test.—The random character of fluctuations in regional yields of wheat becomes quite evident from the analysis of probabilities in the last column of Table I. These are summarized below in a frequency distribution by size of probabilities:

Probability (class intervals)	Number	Frequency by 0.1 interval
.02–.05	1	2
.05–.10	1	
.10–.20	5	5
.20–.30	8	8
.30–.50	6	3
.50–.70	6	3
.70–.80	6	6
.80–.90	5	5
Above .90	1	1

These probabilities indicate how great or how small is the chance that divergence between observed frequencies of various phase durations and those expected for random series of the same duration may be explained by fortuitous causes (sampling variation). Usually divergence is considered significant when the probability of its chance occurrence is below .05 (5 per cent confidence level), that is, when it may be expected that in not more than one case out of 20 could chance cause the divergence. When greater assurance is desired, only those divergences are regarded as significant for which probabilities of occurrence by chance are below .02, or even below .01 (2 per cent or 1 per cent confidence levels).

From the tabulation it may be seen that only in one case (Rumania) is the probability below .05, and that it is below .1 though above .05 in case of yield on harvested area in the eastern portion of the United States Soft Winter area.[39]

But since as many as 39 series were tested, it would be expected that in one or two tests probabilities within the limits .02 to .05 would be obtained and, in two to four cases, probabilities within the limits .05 to .10. Only two probabilities as low as .10 result from our test, and this indicates that such occurrences may be explained by chance. Five cases have probabilities lying within the lim-

[38] When limits of the class intervals in the distribution of combined phases unadjusted for ties are shifted so that the mean deviation for the 39 series (1.56 years) would fall approximately in the middle of the class intervals—starting at the lower limit with 1.31 instead of 1.30—the frequency distribution will be nearly symmetrical.

[39] The same series tested for the period 1885–1939 resulted in an even lower probability, lying within the limits .01 to .02. For this shorter period, the series on yield of wheat on sown acreage for the entire United States Soft Winter region also results in a low probability lying within the limits .02 to .05. In these cases, the probability was low because occurrence of 1-year phases was considerably smaller and that of 2-year and longer durations was larger than expected in random series. This means that fluctuations in yield in the United States Soft Winter Wheat area occurred in cycles of longer duration. A glance at the curve representing yield of United States Soft Winter in Chart 1 (p. 299) will explain why the inclusion of data for years preceding 1885 made the probability of randomness greater. In the early years several alternations of small and larger crops occur from one year to the next.

its .10 to .20, but from 39 tests occurrence of five to eight of that size probabilities is within the range of chance. This is true also of appearance in more than eight cases of probabilities lying between .20 and .30.

The distribution of probabilities in our frequency distribution is not very regular when adjusted by equal class intervals of .1 of a unit, but our sample of series is too small and larger regions are too unequally represented[40] to justify expectation of regular distributions by such small class intervals. If we divide all probabilities into three larger groups, the distribution (by equal intervals) appear to be more even. Note the tabulation given below:

Probability	Number	Frequency per 0.1 interval
Below .30	15	5
.30–.70	12	3
Above .70	12	4

Even here low probabilities, below .30, appear more frequently per equal class interval. The difference, however, is hardly significant for so small a sample as ours. Perhaps it may be due to concentration of our attention upon regions where divergence from random fluctuations appeared more evident.

The value of the probability for the aggregate of the 39 series, based on the product of the probabilities individually observed in these series, was found to be as high as .86.[41] Under such circumstances, it is safe to conclude that fluctuations in yields in major wheat-producing regions with quite various climatic characteristics do not diverge significantly from fluctuations of random series. There are regions where yields fluctuate in somewhat longer cycles, but these regions do not have peculiar climatic characteristics. In other regions, yields tend to alternate in consecutive years, but once more such fluctuations are not peculiar in particular climates, and they are not so pronounced that divergence would be significant. When the divergence does appear to be significant, as it does in a few cases, it may be explained by chance when the sample as a whole is analyzed. Chance and not regularity apparently dominates fluctuations in yields from year to year in individual regions. Chance dominates also the divergences between regions as to types of fluctuations in their yields.

The application of the Wallis-Moore test to our sample of series in yields demonstrates once more that it lacks sensitivity to trend (p. 299). Indeed, in those series which have quite definitely rising or declining trends, low probabilities of randomness do not appear in greater proportion; and the average probability of randomness for these series, as for the sample as a whole, approximates one-half.[42]

However, the lack of sensitivity of the Wallis-Moore test to trend does not invalidate the conclusion drawn previously from the test of 39 series of yields. Presence or absence of trends is easily established through a smoothing of series by moving averages (as it may be seen from Chart 1, p. 299); and the causes determining these trends are mostly different from those determining short-term fluctuations in yields. Weather factors, which dominate the latter, may find their reflection in depressions, bulges, and other irregularities

40 Special attention to the United States Soft Winter region as well as to Southeastern Europe resulted in greater representation of these two regions, compared to others. Within these regions there appeared fluctuations in yields diverging substantially from those characteristic of random series. Some of the series are for partly overlapping areas: Rumania and Southeastern Europe (East), Hungary, and Southeastern Europe (West). In the United States Soft Winter region, yields on sown and harvested area also gave double representation of the same area.

41 This probability was determined by following the method of combination of probabilities from independent tests of significance developed by R. A. Fisher (*Statistical Methods for Research Workers*, 7th ed., rev. and enlarged, Edinburgh and London, 1938, Sec. 21.1, pp. 104–06).

42 The "Goutereau constant" (see footnote 26) reveals the presence of trend in series better than the Wallis-Moore test. Indeed, computed for series on yields that do not have definite trends (e.g., New South Wales, Australia) or for regions that have very slight trends (e.g., the United States Soft Winter area—Chart 1, p. 299), the Goutereau constant does not diverge significantly from the values expected in the case of a random series. This is true on the assumptions both of normal and of rectangular distributions. But in the case of series with definite and steeper trends (e.g., Northern Europe, western portion, and United States Spring Wheat—Chart 1), the Goutereau constant differs significantly from its theoretical values for a random series. These latter series cannot be classed as random according to this test, while the Wallis-Moore test did not indicate this difference.

in trend lines, rather than in their general direction.[43]

The lack of sensitivity of the Wallis-Moore test to smooth and flat cycles (p. 299) must be regarded as more disturbing. In this respect, the conclusion from the test must be not that it disproves the existence of such cycles in yields, but simply that such cycles, if any, are of small importance in comparison with random year-to-year fluctuations. This means that the economic meaning of yield cycles must also be small in comparison with random fluctuations in yields. The situation is different, however, in cases when the cycles are of long durations, e.g., 20 to 40-year cycles. In long cycles, small cyclical changes from one year to the next, unimportant in comparison to large year-to-year fluctuations, become important when distant years are compared. Their amplitude may be large compared to random fluctuations. Consequently, in the presence of such cycles, yields will vary at a low level when the cycle is at its trough, and at a high level when it is at its peak. Existence of such cycles, at least of strictly periodic ones, has not been proved as yet in weather fluctuations (pp. 294–97). Although there is no more chance of proving the existence of long cycles in crop fluctuations, the Wallis-Moore test does not assure us that such long cycles do not exist.

There is a possibility that the wide random fluctuations in yields may even conceal cycles of relatively short duration, the amplitudes of which are not so small as to be regarded as economically unimportant. Such dangers are illustrated by the fact that the Wallis-Moore test, when applied by the authors to the annual data on pig-iron production in the United States during 1877–1936, did not indicate a very low probability for the hypothesis that pig-iron production fluctuates at random.[44] When the test was applied to monthly production of pig iron for the same period, the results indicated quite clearly that pig-iron production did not fluctuate at random; and cycles of wide amplitude and of relatively short duration in pig-iron production are generally recognized.

Results of the Test on Output Fluctuations

Total outputs of wheat in the eight principal wheat-exporting areas of the world and in the five principal wheat-importing areas of Europe were studied, with a view to determining extent to which they may be regarded as random series.[45] The four chief wheat exporters of the interwar period, and in addition British India, Southeastern Europe, Algeria and Tunisia, and Russia, are included among the exporting areas. Among European importers, total outputs are shown together for the British Isles, Low Countries, and Scandinavian countries, while wheat outputs for Germany, France, Italy, and Spain are shown separately. In all, 13 series of total outputs of wheat were tested. Results of the test are summarized in Table II, which gives the same information as in respect to yield series.

The rapid expansion of acreage under wheat, particularly in the new exporting countries, resulted in a greater growth of the total wheat output.[46] Consequently, in most regions included in this test, regional wheat outputs were rising. Outputs in all eight exporting regions show pronounced rising trends, and those for Argentina, Canada, Australia, and

[43] Bennett, "Trends of Yield," p. 82.

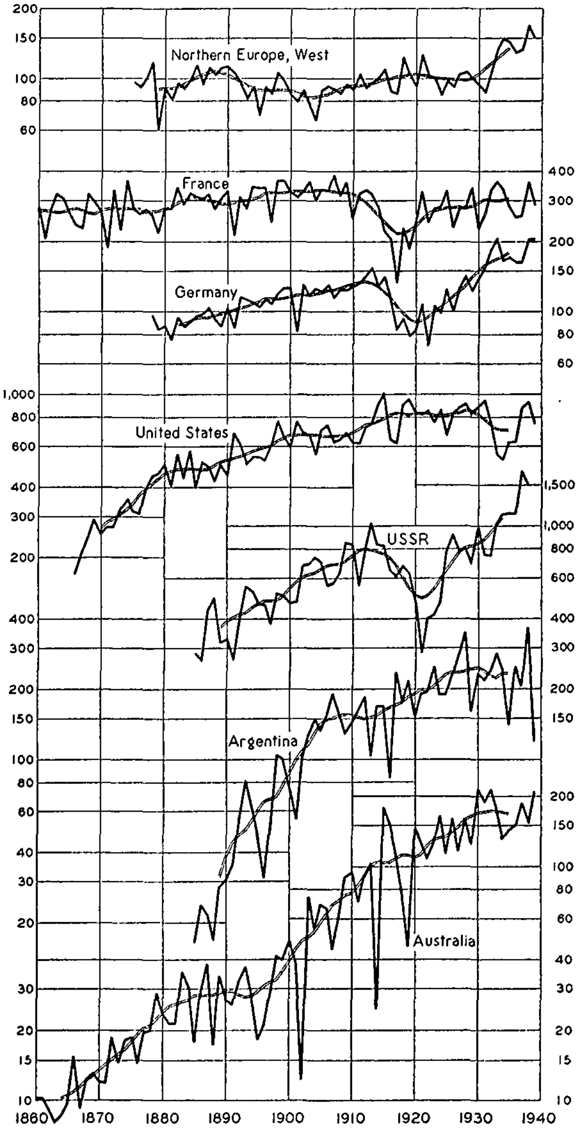
[44] See *Technical Paper*, p. 48. The authors obtained a probability as large as .21 for the hypothesis that annual production of pig iron fluctuates at random. Seven out of the 39 series in yield that we tested have probabilities of randomness smaller than this. But the probability obtained for monthly data on pig-iron production is extraordinarily minute, less than .00005. The authors correctly emphasize that the time unit used in time series may affect conclusions. Data recorded frequently may be highly correlated serially, while those recorded infrequently may be entirely uncorrelated. Meteorological data also show such characteristics (pp. 295–96). But for crop statistics a year is the shortest time unit to be used.

[45] Variations in wheat outputs in the principal exporting and importing countries, with particular reference to their intercorrelations, will make the subject of a subsequent part of this research.

[46] According to Bennett's estimate, the "world" wheat acreage increased from 198 million acres on the average for 1885–89 to 312 million acres on the average for the five years centering around 1928, or 58 per cent. As there was a slight rising tendency also in the "world" yield of wheat per acre, total production increased during the same period in still greater proportion, namely about 85 per cent ("World Wheat Crops, 1885–1932," p. 264).

even Russia were very steep. Outputs in several European importing regions also were rising, with the exception of northwestern Europe and France, where they were more or less stable, or in the British Isles, where they were even falling. Chart 4 presents (on logarithmic scale) annual outputs of wheat for some of the regions included in the test. Trend lines, in the form of 9-year moving averages (weighted), also are shown there.

CHART 4.—ANNUAL PRODUCTION OF WHEAT, WITH TRENDS, IN SELECTED COUNTRIES*
(*Million bushels*)



* Sources of data indicated in Appendix Note.

The presence of steep trends in most of the regional outputs indicates that they cannot be regarded as random series in this respect. Under such circumstances it is rather surprising that only 3 out of the 13 series tested show significant divergence from a random series, as is indicated by a probability of randomness below .05 (see Table II).[47] In all other cases, probabilities that the respective series do not diverge from random series are above .2, and in four cases they exceed .5. It is true that three or even two cases of significant divergence from random series out of a small sample of 13 (or 12) point to a greater variance of the fluctuation in wheat outputs from the random fluctuations than is observed in relation to fluctuations in wheat yields. Indeed, out of 13 series on wheat yields for the same areas and the same periods, only the doubtful series on wheat yields in Spain shows a significant divergence from the random series. If we disregard this last series, variations in yield per acre in the remaining 12 areas conform closely to the hypothesis of their randomness, while the introduction in the output series of such nonrandom components as rapidly increasing acreages in most of the exporting and some of the importing regions results in the appearance of two significantly nonrandom output series—those for Russia and Argentina. It also causes greater divergence from random characteristics in the fluctuations of outputs, as compared to those of yields per acre, in such areas as Canada, Australia, and the United States. Frequency distributions of observed phase durations in outputs and in yields per acre, compared with expected distribution for random series, are shown for these areas in Chart 5. It may be seen from this comparison that distributions of outputs diverge more from those expected for a random series than do distributions of yields. In the first, the number of phases of long duration—3 years and longer—increase, while the number of 1-year phases becomes smaller, and this removes them farther from

[47] Spanish crop statistics for years before 1901 are so unreliable, particularly in relation to acreage and consequently to yield per acre, that the series for Spain should not be included in the test. Disregarding it, there remain only 2 series out of 12 with significant divergence from random series.

the distribution expected in case of random fluctuations.

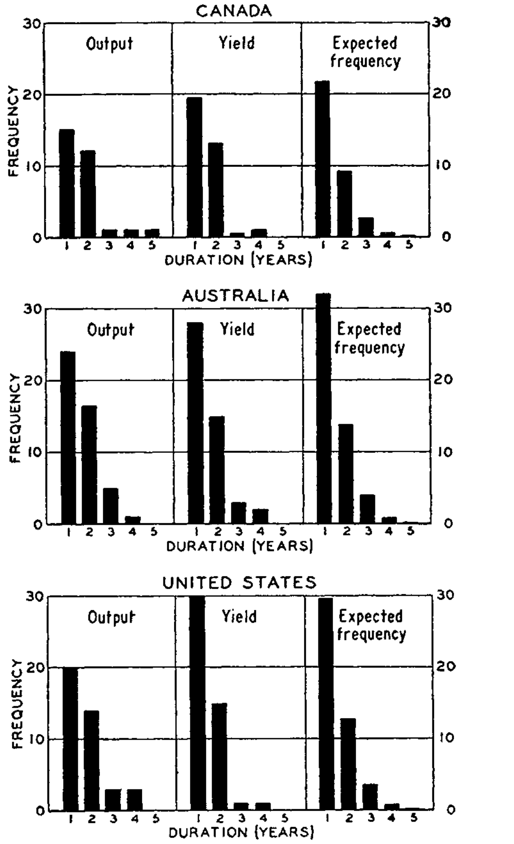
It may be seen from Table II that the average duration of combined phases in the fluctuations of outputs is longer than theoretically expected in all cases, except Germany and Italy. Generally speaking, fluctuations in outputs show fewer phases of short duration and more longer phases than those in yields. This may be substantiated by the following frequency distributions of phase durations in outputs and in yields for 13 series included in Table II when these series are combined:

Duration of phase (*years*)	Number of phases	
	Output	Yield
1	286	330
2	140	143
3	44	40
4	18	13
5	4	..
Total	492	526

The average duration of phases in fluctuations of outputs is 1.61 years and that of yields is 1.50 years. The latter is very near to the average theoretically expected for a random series—about 1.49 units in series with 50 to 80 years—but significantly smaller than that for outputs. Prolongation in the duration of phases and consequently of that of "cycles" in output fluctuations is caused by the fact that a rapid and continuous increase in acreage in some years is proportionally greater than small declines in yields. Thus, for a certain number of years of rapid acreage expansion, total outputs are continually growing in spite of slight fluctuations in yields per acre. A rapidly declining trend may produce the same effect in fluctuations in outputs. It must be noted, however, that even such steeply rising trends as appear for Canada and Australia did not cause fluctuations in their outputs to diverge significantly from random sequences. Indeed, the probabilities that Canadian and Australian series on wheat outputs do not diverge significantly from the random series are relatively high; they lie between .20 and .30 for Canada and between .30 and .50 for Australia (Table II).

In spite of the fact that divergences of the individual output series from the random series are more numerous and more pronounced than those observed in relation to yield series, the sample of 13 wheat production series considered as an aggregate still conforms with the hypothesis of the random sequence of variations. Indeed, the value of the probability for

Chart 5.—Frequency Distributions of Phase Durations in Outputs and Yields of Wheat for Selected Countries Compared with Expected Distribution for Random Series*



* Data mainly in Table II.

the aggregate of 13 series in wheat outputs, based on the product of the probabilities individually observed in these series, was found to be .06. This still exceeds the 5 per cent confidence level, which is usually regarded as the lowest requirement for a significant divergence from a tested hypothesis. The same probability for 12 series, excluding the doubtful series for Spain, is as high as .14. These probabilities for the aggregate of series on wheat outputs must be compared with similar probabilities for the aggregate of 13 and

12 series on wheat yields for the same areas and the same periods. The latter were found to be as high as .40 and .74 respectively.[48]

This comparison clearly demonstrates that the series on wheat yields are in better conformity with the hypothesis of their randomness than are the production series, but still it may be concluded that, though fluctuations in regional total outputs of wheat diverge more from random fluctuations than those in yields, they continue to be dominated by random factors more than by systematic ones.

III. CYCLES IN WHEAT YIELDS

From the test for randomness of regional yield series, the conclusion emerged that regional yields of wheat fluctuate at random in practically all important wheat-producing regions of the world with quite different climatic characteristics. In some regions fluctuations in yields diverged substantially from the pattern characteristic of random series, but in few regions could these divergences be regarded as significant, and even in these cases they might be caused by chance.

However, some important information on character of fluctuations in yields was disregarded in this test. Direction of fluctuations only, not their magnitude, was considered. The smallest variations in yield were regarded of equal value to the widest swings, in so far as they produced changes in direction of movements from a rise to a decline or vice versa. All these changes in direction were considered as turning points—peaks or troughs of cycles —and the items between consecutive troughs, or consecutive peaks, were regarded as forming a cycle with two phases—expansion and contraction. In some cases the peak was only slightly above the adjacent troughs, and the consecutive items of series formed not more than a slight ripple, while in other cases changing items of series produced a well-pronounced swing up and down.

It is natural to ask: Could not this equal treatment of fluctuations of various magnitudes lend to our series of yields a greater appearance of randomness than they would have if the fluctuations were treated with a certain degree of discrimination in regard to their magnitude? Such a question is especially legitimate in the case of yield statistics, since small variations in yields are not infrequently within the limit of errors of crop estimates, and these errors may have the characteristics of fortuitous occurrences. For this reason, it seems advisable to undertake further analysis of yield series with a view to eliminating small movements in yields. Instead of counting them as separate cycles, we may regard them as a kind of ripple upon wider movements. Such smoothing of saw-tooth contour in curves representing time series is a usual practice when time series are analyzed in various components. Hence it was advisable to choose some objective standards for elimination of such minor movements in yield series.

Two methods of segregating minor movements in yields from larger ones, which may be called cyclical fluctuations, were applied in further analysis of 25 regional yield series. We shall call them Method II and Method III for identification of cycles in contrast to Method I, when cycles are counted between succeeding peaks.

In Method II, cycles were counted between the points of up-crossing (or down-crossing) of the line representing annual yields with the trend line, which in our case is a weighted 9-year moving average.[49] This method of counting cycles excludes all small movements that are too weak to change the position of yield with respect to the average yield for neighboring years. That is, declines from preceding peaks are not counted as turning points in a cycle when yields, even at their lowest points, remain above the moving average; and rises from preceding troughs, which even at their highest points remain below the moving average, are likewise not counted.

A glance at Chart 6 will clarify the meaning of this procedure. The chart shows, for a sample of six regional series from the larger

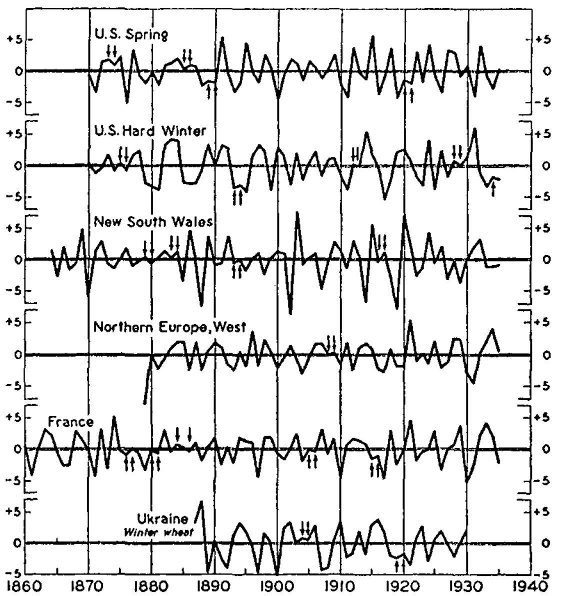
[48] For the method of determining the probabilities for the aggregates of series, see footnote 41.

[49] Obtained by taking 3-point averages of 7-point averages, the final averages give weights of 1, 2, 3, 3, 3, 3, 3, 2, 1 to successive years.

number included in this study, short-term fluctuations in yields of wheat around the respective trends taken as horizontal lines. The upper curve, representing fluctuations in yields in the United States Spring Wheat belt, shows several examples of small movements in yield that would be counted as cycles according to Method I but would not be counted under Method II. The 2-year periods between 1873 and 1875 and between 1884 and 1886 are not counted as cycles, because in these cases the troughs do not descend below the trend line. The 2-year periods between 1888 and 1890 and between 1919 and 1921 are likewise not counted as cycles, because peaks in 1889 and 1920 do not rise above the trend.

CHART 6.—WHEAT YIELDS PER ACRE: DEVIATIONS FROM TRENDS, FOR SELECTED REGIONS*

(Bushels per acre)



* Sources of data on yields indicated in Appendix Note.

This method, however, does not eliminate from counting as cycles some very slight movements in yields, when these yields in their initial positions are very close to the moving average. In such cases, slight changes may bring the yield from below the trend line to above it or vice versa. Several such examples appear on the chart in fluctuations of yield of wheat in New South Wales, as in the years 1878–80 and 1915–17.

It therefore seemed advisable to apply another more direct and deliberate method of eliminating slight movements in yields from counting as separate cycles. According to this third method, cycles are counted between consecutive troughs or consecutive peaks (whichever occurs first in the series); but some of the peaks and some of the troughs are not counted.[50]

The basis for omission of certain peaks is the smallness of elevations above the adjacent troughs. Likewise, small depth of troughs in respect to the adjacent peaks is the basis for their elimination. As a standard of comparison, the standard deviation, computed for all deviations of annual yields for a given series from respective trend lines, is used. When the elevation of a peak above one or both of the adjacent troughs is smaller than a half of the standard deviation, or when the depth of a trough below one or both of the adjacent peaks is smaller than a half of the standard deviation, such peaks and troughs are omitted.[51]

A glance at Chart 6 will show what kinds of minor movement in yields were eliminated from counting as separate cycles in the series on yields in accordance with Method III, where small arrows indicate peaks and troughs that were omitted. They mark small notches on the top of a cycle, small jags in the bottom, or a ripple on a rising or declining phase of a cycle. This chart shows that eliminations of minor movements were conservative as compared with the usual practices applied in the analysis of time series in order to identify cyclical

[50] Positions of all peaks and all troughs were determined from charts representing deviations of annual yields from respective trend lines, as represented in Chart 6, not from original series of yields. The latter was used to determine turning points in the test for randomness in variations in yield as discussed in the preceding section.

[51] When a peak was omitted, the less deep of the adjacent troughs also was disregarded. With the omission of a trough, the lower of the two adjacent peaks was dropped. In order not to prolong flat cycles excessively, the rule was followed that in no case should two consecutive troughs or two consecutive peaks be omitted, even if their omission were required by the preceding rules. The more conspicuous one was always preserved. Generally speaking, in case of doubt, the respective peaks or troughs were kept rather than omitted.

movements as different from minor fluctuations. No smoothing of data by short-term moving averages was applied, since such smoothing has a tendency to produce cycles of a certain length even when strictly random series are smoothed.[52]

By applying Methods II and III for segregating minor fluctuations in yields from larger ones, we obtained two sets of cycle determinations for each of the 25 regional yield series. Cycles determined according to these two methods are not always identical, but they are fairly similar for the same regional yield series, if judged by such characteristics as their average durations (see p. 313); but they are substantially different from cycles identified by Method I, the expansion and contraction phases of which were used in the test for randomness in the preceding section.

To summarize, for each of the selected regional series "cycles" were identified by three methods: (I) taking intervals between each two successive peaks in the series of annual yields; (II) taking intervals between consecutive up-crossings or down-crossings, whichever occurs first in a series, of the lines representing annual yields with the trend lines for respective series; and (III) taking intervals between consecutive troughs or peaks, whichever occurs first, after elimination of some minor peaks or troughs.[53]

Selection of series on yields to be included in the sample of 25 series for further analysis was done in such a way that all major wheat-producing regions of the "world" (including Russia) were represented without duplications. The major regions used in the study of trends (p. 300) are usually represented by one series each. In some cases, these regional series relate to portions of the respective regions, because sufficiently reliable crop statistics for periods of considerable duration are available for only these portions. However, in some of the major wheat regions (such as Northern Europe, Southeastern Europe, and Australia) several subregional yield series are included instead of one regional because of the large size or nonhomogeneous character of these regions. Thus the sample of 25 series may be regarded as fairly representative of the wheat "world" in all its variety.

Various characteristics of "cycles" in fluctuations of regional yields of wheat were measured. Durations and number of cycles are given in Table III, while in Tables IV and V are summarized various measures of the amplitude of cycles. Frequency distributions of cycle durations (in years) are given only in respect to cycles identified by Method III. The measures of amplitudes also are given in greater detail in relation to cycles identified by Method III. They are summarized in the last six columns of Tables IV and V. These were found to be fairly similar to the cycles determined by Method II. Certain measures of amplitudes are given, however, also for cycles determined by Method I.

Duration of Cycles

Duration of cycles[54] in the fluctuations of yields of wheat is perhaps the most important characteristic of these fluctuations, in so far as the problem is to compare wheat "cycles" with cycles in other economic phenomena. Coincidence in timing of cycles is usually regarded

[52] See Eugen Slutzky, "The Summation of Random Causes as the Source of Cyclic Processes," *Econometrica,* April 1937, V, 105–46 (this is a revision of an article published in Russian in *The Problems of Economic Conditions,* Conjuncture Institute, Vol. III, No. 1, Moscow, 1927); E. L. Dodd, "The Problem of Assigning a Length to the Cycle to Be Found in a Simple Moving Average and in a Double Moving Average of Chance Data," *Econometrica,* January 1941, IX, 25–37.

[53] Peaks and troughs in this case may not, and in a few cases actually did not, coincide with peaks and troughs as established by the first procedure, in which original series on yields were used, since here peaks and troughs were identified by using deviations from respective trend lines. The practice used in the two latter procedures of counting cycles between consecutive up-crossings or down-crossings, or between consecutive troughs and peaks whichever occurs first in a series, may be criticized as inconsistent, since different procedures are applied in different series. However, such practice has the advantage of leaving shorter "tails" at the beginning of series and thus of utilizing a greater portion of available information in the analysis.

[54] The term "cycle" is used here to designate sequence of items in a time series—in our particular case, sequence of annual yields of wheat—between consecutive troughs (or peaks) or between up-crossings (or down-crossings) of the lines representing annual data with the trend lines in respective series, without consideration of how regularly cycles of various duration recur. The question whether fluctuations in yields of wheat are sufficiently regular in their occurrence to be called cycles is discussed below (p. 319).

as an indication of a possible causal relationship between fluctuations in two phenomena, rather than similarity in other characteristics such as amplitude of variations. Variety of amplitudes in fluctuations of various economic phenomena, regarded as closely connected with economic cycles, is a well-known fact; and differences in the magnitude of variations of such phenomena are usually rationally explainable. But some kind of systematic relationship in timing of cycles, their coincidence or opposition, or some systematic lag in cycles of one phenomena in respect to cycles in others, is always considered one of the first indications of a possible causal relationship. For this reason, it is advisable to present certain details regarding durations of cycles in yields of wheat.

Average durations variously measured.— Average durations of cycles measured between any two consecutive peaks, without any eliminations, have close relationship to average durations of phases of these cycles given in Table I, where the results of the test for randomness in fluctuation of yields are summarized. In so far as it was concluded from the test that distributions of observed phase durations generally do not differ significantly from those expected in random series, the same conclusion holds also for "cycles" composed of expansions and contractions. The average duration of these cycles for all 25 regional series taken together is 3.10 years— slightly longer than that expected in a random series;[55] but the divergence is too small to be significant, as was shown in the earlier analysis of phase durations (pp. 303–06).

The average duration of cycles identified by the two methods of eliminating minor movements in yield from counting as separate cycles (pp. 310–12) happens to be surprisingly close for the 25 selected series taken together. It is 3.52 years for Method II and 3.55 years for Method III. Average durations of cycles identified by the two methods also are sufficiently close for subgroups of regional series grouped by geographical areas, as may be seen from the following tabulation giving these average durations in years:

Groups of series	Method II	Method III
7 North American series..	3.62	3.71
7 European series (including Algeria)	3.31	3.36
4 Australian series	3.56	3.68
5 Russian series	3.77	3.53
20 series (ex-Russia)	3.49	3.55
25 series	3.52	3.55

Differences in the average duration of cycles identified by the two methods are substantial in the case of some individual regional series (Table III); but even here, with few exceptions that may be explained by some fortuitous factors,[56] the agreement between the two methods is sufficiently close. Such agreement in results, obtained by two procedures different in their assumptions, indicates that the standards chosen for elimination of minor fluctuations in yields from counting as separate cycles happen to be of about equal value in both methods.

The elimination of minor fluctuations in yields by these two methods thus resulted in a prolongation of the average duration of cycles in yields of wheat from 3 years, characteristic of random fluctuation, to about 3½ years or 42 months.

It is of interest to note here that such duration of cycles is characteristic of one type of business fluctuation established by several students of business cycles, particularly in relation to business cycles in the United

[55] The expected average duration of "cycles" for random series of 50 to 80 items ("years") would be slightly below 3.00 items, since the expected average duration of phases in such series would be equal to about 1.49 (p. 304).

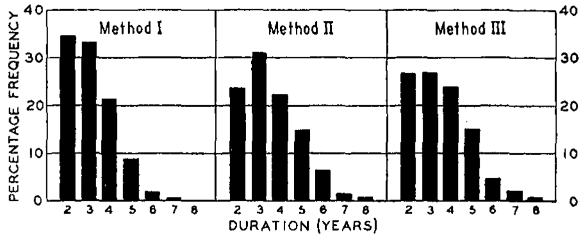
[56] In 5 of the 25 regional series on yields, namely, for Eastern United States, South and Western Australia, Ukraine (winter wheat), and the North Caucasus (spring wheat), differences in the average durations of cycles identified by the two methods are rather large. In some of these series, the average duration is longer for cycles identified by Method II; in others, for those identified by Method III. The principal cause of these divergences is that in some cases there are substantial fluctuations in yield around a high or a low level in respect to the moving average; and, consequently, such fluctuations are not regarded as separate cycles according to the second method, but they are counted by the third. On the other hand, some small variations in yield in the neighborhood of the average yield are eliminated from counting by the third method, but they are not excluded by the second. A scrutiny of the curves representing yields in Western Australia and in the Ukraine, given in Chart 1 (p. 299), will bring out the causes of the divergence between the results obtained by the two methods.

States.[57] We mention this coincidence simply to indicate that fluctuations of such average durations in economic phenomena are called cycles, when they have certain characteristics of regularity in their recurrence. Before discussing the question of how legitimate it is to call oscillations in yields "cycles," it is therefore necessary to see what degree of regularity is observed in these oscillations. In doing so, it will be necessary to study not only average durations but also variations in durations from one case to another, which may be represented by frequency distributions of cycle durations.

Distribution of durations for all series.—It is advisable to present here first the general picture of the frequency distribution according to duration of the cycles, identified by the three procedures (p. 312), in all of the 25 series included in our sample. This will show to what extent the elimination of minor fluctuations, following Methods II and III, affects frequencies of cycles of various length differently. Close coincidence in the average duration of cycles identified by these two procedures does not mean that their distributions by length of durations will also be similar.

Chart 7 presents three frequency distributions of durations of cycles identified by the three methods for all 25 series taken together. These frequencies are shown in percentages of the total number of cycles identified by each method.[58] Comparison of these distributions makes it clear that elimination of minor fluctuations by both procedures results in a smaller relative frequency of short cycles of 2- and 3-year durations.

CHART 7.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN YIELDS OF WHEAT PER ACRE MEASURED BY VARIOUS METHODS FOR 25 SELECTED SERIES COMBINED*



* Data in footnote 58.

In the distribution on the left side of the chart, which represents cycles measured between consecutive peaks with no omissions, the most frequent are cycles of 2-year duration. They comprise more than one-third of the total number of cycles. Three-year cycles are only slightly less frequent, and they comprise also nearly one-third of the total number, while cycles of duration longer than 3 years taken together make a little less than one-third of the total. Of these, 4-year cycles comprise about one-fifth of the total, and 5-year cycles less than one-tenth. Cycles longer than 5 years are rather exceptional.

The other distributions, representing cycles after elimination of minor fluctuations according to two procedures, have one common characteristic: in both, short cycles of 2- or 3-year duration are less frequent than in the first distribution, while 4-year, 5-year, and longer cycles are relatively more frequent. But there is also a certain difference between the last two distributions. The frequency distribution of cycles counted between the up-crossings (or down-crossings) of lines representing annual yield with respective trend lines (Method II) is characterized by predominance of 3-year cycles. There is no such predominance of 3-year cycles in the third distribution, though they are still slightly more numerous than 2-year cycles. Except

[57] Professor Schumpeter calls these "Kitchin cycles" (Joseph A. Schumpeter, *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*, New York and London, 1939, I, 165, 169). Harold T. Davis, in his new book on economic time series, says that the evidence is very strong that business activity has a cyclical component of about 3½ years (*op. cit.*, pp. 26, 546–50).

[58] All series included in this comparison, except the Russian, are taken for a uniform period beginning from 1885, in order that various duration of individual regional series would not affect the distribution. In absolute numbers these frequencies are:

Cycle durations (*years*)	Number of cycles		
	Method I	Method II	Method III
2	134	67	76
3	129	88	77
4	83	63	68
5	34	42	43
6	7	18	13
7	2	4	6
8	..	2	2
Total	389	284	285

for this difference in the relative frequency of 2- and 3-year cycles, the last two distributions are very much alike: frequencies of 4-year, 5-year, and longer duration cycles are distributed quite similarly in both. Thus the two procedures for elimination of minor fluctuations in yields result not only in cycles of about equal average duration but also in fairly similar distribution of these cycles by length. Under such circumstances, we feel justified in using cycles identified according to Method III for further more detailed analysis of cycles in fluctuation of regional yields of wheat. We select for more detailed presentation cycles identified by this method, because the segregation of minor movements in yields according to it was made with more deliberation and less mechanically than is characteristic of Method II.

Average durations by regions.—In Section II we concluded that there is no systematic relationship between the average durations of phases in the oscillations of regional yields of wheat and climatic characteristics of the respective regions. Variation in the average durations of phase from region to region appeared to be fortuitous (p. 304). In so far as cycles in the oscillations of yields, measured between consecutive peaks without any omissions, consist of these same phases of expansion and contraction, there is no question that their average duration also varies from region to region in a haphazard manner. But the question may arise, whether average durations of longer cycles—3½-year cycles obtained by omitting some of the minor fluctuations in yields from counting as separate cycles—vary from region to region in some systematic way. Average durations of these cycles vary from region to region in not exactly the same order as those for 3-year cycles, since omission of minor movements in yields from counting affected average durations of cycles in individual regions in not exactly the same proportion.

General examination of information on the average durations of cycles in regional yields of wheat, as established by the second and third methods (given in two columns of Table III), also does not leave the impression that these durations vary from region to region in a definitely systematic way. But closer scrutiny of these data is needed. The average durations of cycles identified by the third method are used for this purpose.

A study of the frequency distribution of the average durations of cycles identified by Method III may also be helpful for our need.

If the 25 regions are divided into three approximately equal groups with relatively short, medium, and long average durations of cycles, the following groups are formed within which regions are ranked according to the increasing average length of their cycles:

Regions with average duration of cycles below 3.40 years	Regions with average duration of cycles from 3.40 years to 3.70 years	Regions with average duration of cycles above 3.70 years
1. Italy	1. New South Wales	1. Prairie Provinces, Canada
2. Southeastern Europe, West	2. South Australia	2. Southeastern Europe, East
3. India	3. U.S. Pacific Southwest	3. Ukraine (spring wheat)
4. Volga region (spring wheat)	4. U.S. Spring Wheat	4. Ukraine (winter wheat)
5. North Caucasus (spring wheat)	5. Argentina	5. Victoria
6. Northern Europe, West	6. North Caucasus (winter wheat)	6. Eastern U.S.
7. Algeria	7. U.S. Soft Winter	7. Western Australia
	8. U.S. Pacific Northwest	8. U.S. Hard Winter
	9. Germany	
	10. France	

No North American and no Australian regions are in the group with short duration of cycles; they are all distributed between the two groups with medium and long average duration of cycles. Europe ex-Russia has regions in all three groups, though most of them are in the group with short average duration of cycles. The five Russian regions also are divided among all three groups. The distribution of regions in the above three groups does not indicate much of a systematic relationship between geographic characteristics of regions and the duration of cycles in yield of wheat. It indicates, however, that cycles tend to be somewhat longer in North America and Australia and shorter in Europe ex-Russia.

As Table III shows, the average durations of these cycles vary within a relatively wide range from 2.6 years (Italy) to 4.1 years

(United States Hard Winter). For the great majority of the wheat-producing regions—18 out of 25—the average duration of cycles varies, however, within a much narrower range, from 3.25 to 3.85 years. This is clear from the tabulation below, in which are summarized data given by individual regions in one column of Table III:

Average duration of cycles in yields (*years*)	Number of regions
2.45–2.64	1
2.65–2.84	..
2.85–3.04	1
3.05–3.24	1
3.25–3.44	4
3.45–3.64	9
3.65–3.84	5
3.85–4.04	2
4.05–4.24	2

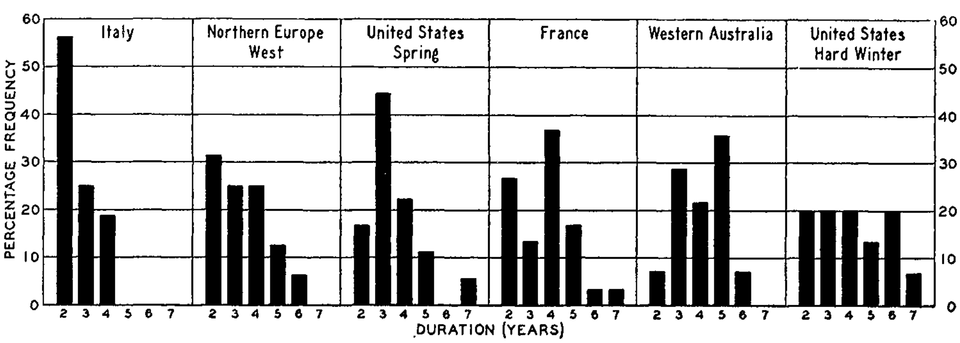
There are only a few regions with average duration of cycles shorter than 3.25 years or longer than 3.85 years, while for most of the regions average durations of cycles fall within this range. The distribution itself appears rather symmetrical for a small sample of 25 regions, and this lends some support to the inference that variations in the average durations of cycles from region to region may be caused by chance.

Distributions of durations by regions.—Average durations of cycles for regional yield series do not indicate, however, how much regularity there is in recurrence of cycles. Distributions of cycles by durations for individual regions or for groups of regions are necessary for this. Chart 8 shows frequency distributions of cycle durations for several regions representative of groups with short, medium, and long average durations of cycles, as given in the preceding tabulation.[59] Frequency distributions are arranged from left to right according to the increasing length of the average duration of cycles. Italy and the western portion of Northern Europe are regions with relatively short average durations of cycles in yields. The United States Spring Wheat belt and France represent regions with medium average duration of cycles. Western Australia and the United States Hard Winter wheat area have cycles of the longest average duration, exceeding 4 years.

Chart 8 shows that in the two first regions the most typical is a 2-year cycle, or alternation from high to low yield in consecutive years. This is particularly characteristic of Italy, where 2-year cycles comprise more than half of the total number, 3-year periods make a fourth, while the remaining cycles are of 4-year duration. No longer cycles were observed in Italy. The characteristic zigzag appearance of the curve representing annual yields of wheat in Italy may be seen in Chart 1 (p. 299). It must be noticed here that no "cycle" was eliminated from these zigzag fluctuations in yields of wheat in Italy by either of our methods for segregation of minor movements in yield.

There is no such preponderance of alternations of high and low yields in the western portion of Northern Europe: 2-year cycles

CHART 8.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN YIELDS OF WHEAT PER ACRE FOR REPRESENTATIVE REGIONS*



* Data in Table III.

[59] Table III gives similar information for all 25 regions.

are still the most frequent, but their number is only slightly larger than those of 3- and 4-year cycles, and a few cycles of longer durations also appear. This may be noticed clearly from the appearance of the curve (Chart 1) representing yield in the western portion of Northern Europe, when compared with the curve for Italy.

In regions with medium average duration of cycles, 2-year cycles are not the most frequent. In fluctuations of yields in the United States Spring Wheat belt, the 3-year cycle is quite typical; nearly half of the total number belong to this group. Next in frequency are cycles of 4 years, while 2-year alternations in yields make less than one-fifth of the total number of cycles, and a few longer cycles appear. The distribution of various duration cycles is much less regular in French yields of wheat. There 4-year cycles are the most frequent, but 2-year alternations are next in frequency, while cycles of 3 years are less frequent even than 5-year cycles. Cycles longer than 5 years are exceptional. The irregular distribution of French cycles in yields occurs in spite of the fact that for France we have the longest record of yield, covering 125 years with 30 cycles included in the frequency distribution.

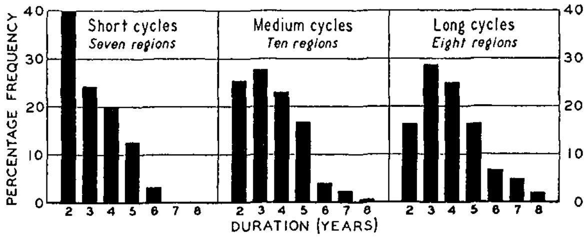
There is also no great regularity in recurrence of cycles in the two regions with long average duration of cycles—Western Australia and the United States Hard Winter area. In Western Australia, the 5-year cycle appears most frequently; but the 3-year cycle is also relatively frequent, composing more than one-fourth of the total number of cycles; and the 4-year cycle a little more than one-fifth. But alternation of high and low yields in consecutive years seldom occurs in Western Australia. The distribution of cycles by their length is rather unusual in the United States Hard Winter area. The frequency distribution at the extreme right of the chart shows that cycles of 2, 3, 4, 5, and 6 years are nearly equally represented in fluctuations in yields of wheat in this area. This combination of cycles of various duration appears clearly also from the curve representing annual yield of wheat in this region in Charts 1 and 6 (pp. 299 and 311).

These illustrations point to variety in occurrence of cycles of various durations rather than to a regular recurrence of a cycle of the same duration. This conclusion is further strengthened by scrutiny of distributions of cycle durations for other regions, shown in Table III. These distributions, though approaching one or another of those presented in Chart 8, have each some individual features. However, this impression may be misleading. It may exaggerate the irregularity in recurrence of cycles in regional yields of wheat. It must here be recalled that, with the exception of France, the total number of cycles in individual series included in the distributions presented in Chart 8 varies between 14 and 18. Frequency distributions with such small total numbers cannot be regular. Similar frequency distributions of business-cycle durations for individual countries (measured in years) frequently do not show greater regularity.

Distributions of durations by groups of regions.—Distributions of cycle durations are much more regular when cycles in several regional series are taken together. Chart 9 (p. 318) gives three frequency distributions of cycle durations for three groups of regions grouped by average durations of cycles in their yields. The frequency distribution at the left represents 7 regions with average durations of cycles below 3.40 years, that in the middle represents 10 regions with average durations of cycles from 3.40 to 3.70 years, and the distribution at the right represents 8 regions with average durations of cycles exceeding 3.70 years.

As it is natural to expect, these frequency distributions do not show such irregularities as appear in distributions for individual regions included in respective groups. Regional irregularities are mutually compensated for, and this may indicate that they are accidental in character and vary independently from region to region, at least to a certain extent. But some common characteristics for regions with short, medium, and long average durations of cycles appear in these distributions. In regions with short average length of cycles, alternation of high and low yields in consecutive years (2-year cycle) is typical. The number of 2-year cycles is nearly equal to the total number of 3- and 4-year cycles taken together. But cycles of longer duration, particularly 5-year cycles, are also represented in this group. Cycles longer than 5 years are rather exceptions in this group of regions. As we have seen, this distribution of cycle durations is typical of several European regions.

CHART 9.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN YIELDS OF WHEAT PER ACRE FOR 25 SERIES IN THREE GROUPS*

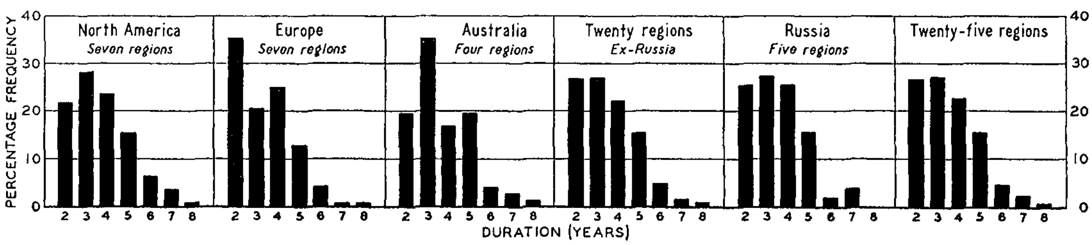


* Data in Table III.

Two other distributions, representing regions with medium and long average durations of cycles, also are asymmetrical, but the 2-year cycle does not predominate in fluctuations in yields in these regions. The most typical in both groups is the 3-year cycle. In the regions with cycles of medium average duration, however, the 2-year cycle is the next frequent. In regions with long average durations, the 4-year cycle usually occurs more frequently than 2-year cycles. Long cycles of 6 and more years are also represented more in this last group, but the principal characteristic of this group is that alternations of high and low yield in consecutive years are not frequent.

Less regularity appears in the frequency distributions of cycle durations for groups of regions arranged on a geographical basis. Chart 10 shows frequencies of cycles of various length (in percentage of their total) separately for groups of regions and all 25 regions.[60]

CHART 10.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN YIELDS OF WHEAT PER ACRE FOR 25 SERIES GROUPED BY GEOGRAPHICAL AREAS*



* Data in Table III.

Of the four geographical groups of regions, that for the 7 North American regions shows the most regular distribution of cycles by length. Most of the cycles in North American regional yields of wheat are of 3- and 4-year durations. They compose more than half of the total number of cycles. There are alternations of poor and good crops in consecutive years, but these 2-year cycles comprise only about one-fifth of the total number. Cycles of 5- and 6-year duration taken together make also about one-fifth of the total number of cycles. Such distribution points to a considerable degree of regularity in recurrence of cycles of 3- and 4-year duration in American regional yields of wheat. The mean average duration of cycles for this group of regions—3.7 years—represents the typical duration of cycles. The regularity in recurrence of cycles in regional yields of wheat in North America is not smaller, for instance, than that in recurrence of business cycles in the United States. It may be mentioned in passing that the frequency distribution of business cycle durations in the United States (as established by Wesley C. Mitchell) is very close to that of cycle durations in regional yields of wheat in North America as shown in Chart 10. We return to this below (see pp. 327–29).

There is less regularity in the distribution of cycles by length in yields of wheat for re-

[60] Durations of series on yields for individual regions included in these groups are various; see Table III.

gions of Europe. Alternations of poor and good yields from year to year are most typical for these regions, as is indicated by the fact that the 2-year cycle appears most frequently. They comprise more than one-third of the total number of cycles in these regional yields. But the 4-year cycles also are frequent in European yields; they are next in number to 2-year alternations of crops, comprising one-fourth of the total number of cycles. Appearance of the two typical durations of cycle—2-year and 4-year cycles—is characteristic of yield fluctuations not only in France but in Germany and in the western portion of Northern Europe. But in other regions of this group, such as Italy, Algeria, and the western portion of Southeastern Europe, 2-year alternations in yields predominate.

In Australian regions, the 3-year cycle in fluctuations of wheat yield is the most common, but the 5-year cycle represents the secondary mode. In Western Australia, indeed, the 5-year cycle occurs even most frequently. In 3 other Australian regions, the 3-year cycle occurs the most frequently, notably in New South Wales, where cycles average shorter than in other major wheat regions of Australia.

Finally, in Russia no particular duration of cycle predominates. About equally frequent are 2-year, 3-year, and 4-year cycles, and 5-year cycles sometimes occur. In this respect, fluctuations in yield of wheat in Russia have characteristics in common with those in the United States Hard Winter and Soft Winter areas, as well as the Prairie Provinces of Canada.

The more regular distribution of cycle durations for the group of 7 North American regions, when compared with that for 7 European and 4 Australian regions, may indicate that fluctuations in wheat yields in North American regions are less interdependent than those in Europe and in Australia. Irregularities in a frequency distribution of cycle durations would tend to compensate to a greater extent when variations in regional yields are independent than when they are more or less closely related one to another, partly because of similarity in weather variations.[61]

When all 20 regions excluding Russia, or all 25 regions included in the study of cycles, are taken together, the distribution of cycle durations become quite regular, though skew. As Chart 10 also reveals, these distributions are much like the distribution of cycles measured between successive peaks without omissions.[62] The only difference is that, in the last distribution, frequencies decline faster from their highest value for 2- and 3-year cycles. But we know that these cycles of 3-year average durations do not diverge significantly from random fluctuations in their distribution by durations. This may indicate that the distribution of longer cycles—those with the average duration of 3½ years obtained after elimination of minor fluctuations in yields—also has many characteristics of random fluctuations.

However, there are certain elements of regularity in recurrence of cycles in the fluctuation in regional wheat yields, which may justify considering them as real cycles, at least not fundamentally different from cycles in other economic phenomena, such as the 3½-year business cycle. Indeed, there are several indications that the average duration of cycles in fluctuations of regional wheat yields of 3½ years has characteristics of a typical, representative average, and not of an abstract average. In more than half of the 25 series included in the study of cycles, the 3-year or the 4-year cycles appear most frequently. In nearly three-quarters of the regions (18 out of 25), one of these two typical durations appears not less frequently than cycles of any other duration. And, finally, in four-fifths of the

[61] The study of correlations among fluctuations in regional yields of wheat for various continental groups of regions, which will be the subject of one of the later parts of this research, leaves the impression that there is less interdependence between fluctuations in regional yields in North America than in Europe, excluding Russia, and in Australia.

[62] In the distributions presented in Chart 7 (p. 314), all series included, except the Russian, cover a uniform period beginning with 1885. In the distributions presented in Chart 10, various series have various durations, as indicated in Table III. The fact that the frequency distribution for 25 series in Chart 7 (Method III) and in Chart 10 are closely similar indicates that the varied duration of series included in the second set of distributions does not affect these distributions appreciably.

regions (20 out of 25), cycles of one of these two durations are most typical, or represent the secondary typical duration. On the other hand, the 2-year cycle, the most typical for random series, is the most frequent in only 4 of the 25 series, all of them in Europe. In several regions, the 2-year cycle appears as a second mode, while the most frequent are 3- or 4-year cycles.

The persistence of 3-year and 4-year cycles in the fluctuation of regional wheat yields, when minor movements in yields are disregarded, points to a certain degree of regularity in the recurrence of cycles of that duration which justifies us in calling these fluctuations cyclical.

Amplitudes of Cycles in Yields of Wheat

Here the discussion of the magnitude of variation in yields of wheat in 25 selected regions will be limited to a general presentation of various measures of the amplitudes in cyclical variation of regional yields for the entire durations of the several series, which vary for different regions. The variation in the amplitudes of fluctuation in yields from one region to another, or from one specific group of regions to another, will be presented without going into causal explanation of interregional differences.[63]

Measures of the amplitudes in cyclical variations of yields will here be given for cycles identified by our third method, which deliberately omits certain minor fluctuations in yields from counting as separate cycles by omitting minor peaks and troughs (p. 311). However, it was found advisable also to give certain measures of variations in regional yields that take into consideration every peak and every trough in the respective series, or even every deviation of annual yields from respective trends. Comparisons of the measures of amplitudes in 3½-year cycles with the latter measures of variability in the respective regional yields of wheat supply a base for judging how much the elimination of minor peaks and troughs has affected the average amplitude of cycles in regional yields, and consequently how adequate may be regarded the standards chosen for elimination of minor movements in yields.[64]

Measures of the amplitude of cycles in regional yields of wheat, for 25 selected regions, are given in Table IV in absolute units (bushels per acre), and in Table V in percentages of the mean average yields for the respective regions, computed for the entire durations of series on yields used in the analysis of cycles. As average yields of wheat per acre vary within a wide range among the 25 regions selected for study of cycles (from as low as 7 bushels per acre in the Volga region of Russia, to as high as 32 bushels per acre in the western portion of Northern Europe), interregional comparisons of the amplitudes of cycles in wheat yields are simpler when these are expressed in percentages of the mean average yield.

Two types of measures of amplitudes are given for cycles identified by Method III, after omission of minor peaks and troughs. One ascertains the amplitude of cyclical fluctuations of yield around the respective trends; the other measures the rises from trough to crest and the declines from crest to trough as the difference between the yields in the respective years, without regard to trend.[65]

When all peaks are averaged throughout the duration of series, and likewise all troughs, these averages added together make a fairly good measure of the average amplitude of cycles. The mean average of all rises from trough to crest also gives a fairly good meas-

[63] Variability in regional yields of wheat will be the subject of Part II of this study. In it the attempt will be made to explain differences in regional variabilities in yields in the light of climatic and other characteristics of regions, using a somewhat larger number of regions resulting from division of some of the major wheat regions into homogeneous subregions. However, variability in yields will be studied there for a shorter period, uniform for all regions, for which more reliable crop statistics are available.

[64] For the standard of omission, see p. 311.

[65] The years of troughs and of crests are determined, however, with respect to trends, as the cycles were identified in series of deviations of annual yields from the respective trend lines. This introduces a certain inconsistency, since in a few cases the positions of crests and troughs would be shifted to some neighboring years, if they were determined on series of annual yields instead of their deviations from trend lines. However, such shifts in positions of crests and troughs are few; and when they occur their effect on the magnitude of rises or declines is so small that for our purpose it may be disregarded.

ure of the average amplitude of cycles: likewise the mean average of all declines from peak to trough supply a similar measure. When these two latter measures are averaged, the obtained average swing of cyclical fluctuations in yields is comparable with the sum of the average peak and the average trough in the respective series. The only difference between them is that the sum of the average peak and average trough measures the amplitude of cycles around the trend, while the other measures cyclical swings without regard to trend line.

Close scrutiny of the information on the elements of these two measures, given in Tables IV and V, indicates that the two measures are nearly identical for practically all regions: those in which yields show definite trends as well as those in which yields fluctuate around a nearly horizontal level. This indicates that trends in regional yields of wheat are not sufficiently steep to affect the amplitude of cycles significantly. Consequently, either of these two measures may be regarded as a fairly good measure of the amplitude of cyclical fluctuations in yields of wheat.

The average elevation of peaks above the trend and the average depth of troughs below the trend are given for each series not only for cycles identified after omission of minor movements in yields but also for all peaks and troughs without any omission. This last information is given in columns 5 and 6 of Tables IV and V. Comparisons of the average peaks and troughs for cycles identified after omission of minor movements in yields, as given in columns 9 and 10 of Tables IV and V, with the average for all peaks and troughs without any omission, indicate that in practically no cases did omission of minor peaks and troughs result in an increase of the measures of amplitude of cycles by more than 20 per cent. In most cases, these increases are within the limit of 10 to 20 per cent, though for some regions (e.g., Italy) no differences between these two averages exist, because no peaks and no troughs were omitted according to the procedure used. But generally speaking, the amplitudes of cycles in yield of wheat that were identified after omissions of minor movements in yields are on the average 10 to 15 per cent larger than when amplitudes of all "cycles," including slight ripples, are averaged. To this approximate extent, average amplitudes of cycles in regional yields of wheat were affected by omission of minor fluctuations in yields.

Information on the maximum peak and the maximum trough, as well as the maximum rise from trough to crest and the maximum decline from crest to trough, is also given in Tables IV and V for each of the 25 series on yields included in the analysis of cycles. This reveals a useful additional characteristic of fluctuations in regional yields of wheat. Record high yields per acre and also record crop failures are exceptional phenomena, depending on the coincidence of various fortuitous factors. Record swings from a poor crop to a very large one, or vice versa, are also caused by exceptional factors. Thus, this information alone does not well characterize the usual fluctuation in yields of respective regions. But in combination with the measures of the average amplitudes in cyclical fluctuations in yields and with the measures of variability in yields from year to year—such as coefficients of variability of yields given for every regional series in Table V (column 4)—they supply fairly complete characteristics of fluctuations in regional yields of wheat.

It is not our purpose here to go into detailed interpretations of all these measures of the amplitude in cycles of wheat yields for each region separately. We seek to discover the general characteristics of these amplitudes for all regions together. This may be best achieved by presentation of the limits within which the principal measures of the amplitudes vary, and by presentation of typical magnitudes of amplitudes for the whole sample of 25 series.

Variation of amplitudes by regions.—Amplitudes of cycles in yields of wheat vary greatly among the selected regions. This applies both to amplitudes measured in bushels per acre and to those expressed in percentages of mean average yields in the respective regions. No matter which of the two measures is taken (the mean of the average rise and the average decline, or the sum of the average deviations at peaks and at troughs), the range of variation in amplitudes of cycles in regional yields of wheat is practically the same. The smallest average amplitude of about 1.8 bushels per acre is characteristic of yields of wheat in India; the largest average amplitude of about 8.9 bushels per acre is characteristic of yields of wheat in the Prairie Provinces of Canada. When amplitudes are expressed as percentages of the mean average yields, the smallest average amplitude is about 13 per cent, characterizing cycles in wheat yields in the western portion of Northern Europe; and the largest average amplitude is about 69 per cent, representing cycles in yields of spring wheat in the Volga region of Russia. For both measures of amplitudes—in absolute units and in percentages of the mean average yield—the largest average amplitude of cycles is five to six times as great as the smallest one.

Different regions have been mentioned as having the smallest and the widest amplitudes of cycles in yields, when amplitudes are measured in bushels per acre and when they are expressed in percentages of average yield. This indicates that these two methods of measuring amplitude of cycles may result in a quite different distribution of regions according to the magnitude of amplitudes of their cycles in yields.

In order to give a more general picture of the variation in the amplitudes of cycles in wheat yields among the 25 selected regions, and to show the typical amplitudes for the sample as a whole, below are given two frequency distributions of the average amplitudes of cycles for all 25 regions (measured as the mean average of the average rise and the average decline). The two frequency distributions are quite different in character. The

Average amplitude (*bushels per acre*)	Number of regions	Average amplitude (*percentages*)	Number of regions
1.00–2.49	1	10.0–19.9	3
2.50–3.99	6	20.0–29.9	6
4.00–5.49	11	30.0–39.9	3
5.50–6.99	5	40.0–49.9	5
7.00–8.49	1	50.0–59.9	6
8.50–9.99	1	60.0–69.9	2

amplitudes of cycles in wheat yields, measured in bushels per acre, are distributed nearly symmetrically around their typical value, which is represented by the class interval of from 4.0 to 5.5 bushels per acre. The mean average value of the amplitude (about 4.9 bushels) falls nearly in the middle of this class interval. Eleven out of the 25 regions have cycles with amplitudes within this class interval. Amplitudes of cycles in another 11 regions are almost equally distributed in the two neighboring classes on both sides of the typical value. Thus, the amplitudes of cycles in wheat yields for 22 out of 25 regions fall within the narrower range of from 2.5 to 7.0 bushels per acre.

The average amplitudes of cycles in wheat yields expressed in percentages of the mean average yield for respective regions are concentrated around two typical magnitudes: a considerable number of regions have cycles with amplitudes around 20–30 per cent of their average yields, but there are even more regions in which amplitudes of cycles are around a typical magnitude of 50–60 per cent of the average yield. Thus there are two types of regions in this respect—regions with relatively moderate amplitudes of cyclical fluctuations in yields of wheat, and regions with wide amplitudes of cycles, when these amplitudes are expressed in percentage of the average yield. The latter way of measuring amplitudes of cycles seems to be more appropriate from an economic viewpoint. It is usually more important to know the proportion within which the average yield per acre varies rather than variation in bushels per acre.[66]

Are individual regions distributed in some systematic way between these two groups? Clearly the principal wheat-importing regions of Europe belong to the group with narrower amplitudes of cycles measured in percentages of the average yield. We know already that the smallest amplitude of cycles is character-

[66] In view of the fact that the two measures of the average amplitudes of cycles—(1) the mean average of the average rise and the average decline, and (2) the sum of the average peak and the average trough—are closely equal for practically each of the 25 series, it is unnecessary to present the frequency distributions of amplitudes measured by the second of the two measures. With minor differences in the number of regions within each class as indicated above, the character of both distributions—in bushels per acre and in percentages of the mean average yield—remain the same.

istic of yields of wheat in the western portion of Northern Europe, the region that depends the most on imported wheat. Yields of wheat in the other three wheat-importing areas of Europe (Germany, Italy, and France) also fluctuate within narrow limits. The same may be said of fluctuations in wheat yield of the Eastern United States, another wheat-deficit area. On the other hand, yields of wheat fluctuate within a wide range in practically all major wheat-surplus regions. All of the 13 regions in which average amplitudes of cycles in wheat yields exceed 40 per cent of the average yield per acre are wheat-surplus regions. In few of major wheat-surplus regions are the average amplitudes of cycles in yield of wheat under 40 per cent. Here belong Western Australia,[67] Algeria, the Pacific Northwest of the United States, and also India. In the first two regions, the average amplitude of cycles in yields of wheat is only slightly below 40 per cent. In India wheat acreage fluctuates greatly from year to year under the influence of weather changes; consequently, the relative stability in her average yields of wheat per acre does not mean stability in her total production of wheat.[68] Disregarding India—by no means constantly a surplus area—small amplitude of cycles in yields of wheat is characteristic of only one important wheat-surplus area—the Pacific Northwest of the United States.

No such contrast between the wheat-deficit and the wheat-surplus areas appears when amplitudes of cycles in yields of wheat are expressed in bushels per acre and not in percentages of the average yield. Then most of the wheat-deficit areas are in the group with typical size of amplitude from 4.0 to 5.5 bushels per acre, and many, if not most, of the major wheat-surplus areas also belong to that group.

When regions are grouped by larger geographical areas, the distribution of these areas between the two groups — of small and of large amplitude of cycles in yields of wheat —also appears more or less systematic. Large amplitude of cycles in yields (expressed in percentage of the average yield) is characteristic of Australian and Russian wheat regions, in most of which the average amplitude of cycles in yields exceeds 50 per cent. On the contrary, in European regions, with the exception of the eastern portion of Southeastern Europe (which has characteristics in common with Russian wheat regions), yields fluctuate with narrow amplitudes. North American wheat regions occupy an intermediate position. Wheat yields in the eastern area of the United States and on the Pacific Coast fluctuate within relatively narrow margins in percentage of their average yields, while yields in the Great Plains, from the Prairie Provinces of Canada on the north to the Hard Winter area in the South, fluctuate in cycles of wide amplitudes.

Distributions of regions according to the magnitude of the maximum swing in regional yields of wheat have similar features.[69] In 9 out of the 25 regions maximum swings in yield do not exceed 60 per cent of the average yield. But an even larger group (10 out of 25 regions) have a maximum swing in yield within the limit of 80 to 100 per cent of the average yield. In 4 regions—3 in Australia and one in Russia—instability in yields is still greater, since the maximum swing from good to poor yield and vice versa exceeds 100 per cent of the average yield. Maximum swings in yield for the remaining 2 regions are within the limit of 60–80 per cent of the average yield.

These illustrations warrant the conclusion that amplitudes of cycles in regional yields of wheat, though varying among selected regions,

67 The average amplitude of cycles in yield of wheat in Western Australia would be larger than 40 per cent if crop statistics were taken beginning with 1860, as they are for other Australian series. But the wheat area in Western Australia was extremely small in the earlier years; consequently, fluctuations in yields at that time are little comparable with those of the later period. The exceptionally high yield of 1867, never since repeated, would make the average amplitude of cycles in yields, as well as other measures of variability in yields, unrepresentative for the later period. For this reason, crop statistics for 1860–67 are omitted from the Western Australian series.

68 See C. P. Wright and J. S. Davis, "India as a Producer and Exporter of Wheat," WHEAT STUDIES, July 1927, III, 352. This problem will be discussed with more detail and for regional divisions of India in Part II of this study.

69 By the maximum swing is meant an average of the maximum rise and the maximum decline. These last are shown in the last two columns of Tables IV and V.

are violent enough to be of considerable economic importance. It must be remembered that the regions here selected for analysis of cycles in wheat yields are of large size. Only such important wheat-producing countries as the United States of America, Russia, and Australia are divided into several regions; and the subdivisions, such as the Spring Wheat belt and the Hard Winter area of the United States, or the Ukraine, and the Volga regions of Russia, continue to be major wheat regions of the world. For this reason, it cannot be said that the violence of fluctuations in yields, as presented above, is due to smallness of selected regions. On the contrary, the large size and lack of homogeneity of some of the selected regions result in a certain compensating dampening of still more violent fluctuations in yields in narrower subregions.[70]

Relatively wide amplitudes of cycles in regional yields of wheat are not caused by prominence of crests or troughs. As we have seen (p. 321), omission of secondary peaks and troughs from counting as turning points in cycles increased the average amplitudes of cycles on the average by no more than 10 to 15 per cent. Further evidence of a relatively small conspicuousness of the crests and troughs in yield cycles, even after the omission of secondary peaks and troughs, is found in the fact that the average magnitude of crests and troughs of cycles in yields of wheat equals or slightly exceeds the standard deviation of all deviations of yield from the respective trends in yields (shown in column 4 of Table IV). Thus, amplitudes of cycles in most of the regional yields of wheat are large because of the great variability in yields from year to year, rather than because of the prominence of their peaks and troughs. This characteristic of fluctuations in yields of wheat must be noted here, because it renders particularly difficult the answer to the question: Are these fluctuations cyclical or random in character?

IV. COMPARISONS AND CONCLUSIONS

Fluctuations in yields and outputs of wheat, analyzed in the two previous sections, may now be compared with fluctuations in other crops and with business fluctuations. The first of these comparisons may test our assumption that wheat may be regarded as a crop representative of many others (p. 291). This may be achieved in the most economical way by comparing fluctuations in wheat outputs with those in the volume of crop production for certain countries, for which index numbers measuring such volumes are readily available. The second comparison may help to answer the question: Are the fluctuations in crop yields and outputs materially different from or in some degree similar to fluctuations in business?

To our knowledge, Dr. Brandau, in his study of the relationship between crop fluctuations and business cycles,[71] covers the widest area in this respect. In his analysis he included crop production in 12 countries, of which 6 are in Europe including Russia and 6 on other continents (except Africa). For 4 of the 6 non-European countries, he could not obtain crop statistics for sufficiently long periods, and was consequently obliged to replace crop production by exports of the respective crops. But even after omitting these 4 countries, because fluctuations in exports may not well represent fluctuations in production, the remaining 8 countries fairly represent the agricultural production of Europe, North America, and Australia, which are also mainly represented in our analysis of wheat yields and outputs. In view of this, it seems advisable to use Brandau's index numbers[72] of the volume of

[70] This problem will be discussed in more detail in Part II of this study.

[71] Georg Brandau, *Ernteschwankungen und wirtschaftliche Wechsellagen, 1874–1913 (Beiträge zur Erforschung der wirtschaftlichen Wechsellagen: Aufschung, Krise, Stockung,* Heft 14, Jena, 1936).

[72] Certain broad information concerning these are summarized below:

Country	Period covered	Total number of crops	Number of cereal crops
Germany	1878–1914	11	4
England	1884–1914	7	3
France	1871–1913	6	4
Austro-Hungary	1881–1914	5	5
Rumania	1886–1914	4	4
Russia	1871–1914	6	6
United States	1866–1914	10	6
Australia	1860–1914	7	4

Brandau's index numbers are weighted arithmetic crop production in our comparisons. Here we shall limit these comparisons to a single characteristic—the duration of cycles.

Cycles in Wheat and in Other Crops

In view of the fact that cycle durations in outputs of wheat in countries with rapidly expanding wheat areas tend to be somewhat longer than cycles in yields (p. 309), it was preferable to take for comparison with Brandau's indexes of the volume of crop production 13 series on total production of wheat in the principal wheat-exporting and importing areas[73] rather than a larger sample of 25 regional series on wheat yields.

Two methods of determination of cycles were applied to each of the 13 regional series on the total production of wheat: (1) by measuring their durations between every two consecutive peaks in annual data on production, and (2) by measuring them as intervals between every up-crossing (or down-crossing) of the lines representing annual production with the respective trend lines. Corresponding cycles were identified in each of Brandau's index numbers of the volume of crop production.[74]

In order to have larger samples of cycle durations for comparison, frequency distributions of cycle durations are taken for the entire sample of 13 series in wheat outputs, and for Brandau's 8 index numbers of the volume of crop production. These percentage frequency distributions of cycles in the two kinds of series are shown in Chart 11 (p. 326).[75]

The cycle durations measured between successive peaks in the respective series are quite similarly distributed for both wheat outputs and volumes of crop production, and their distributions are substantially the same as the distribution of similar cycles in wheat yields, as shown in Chart 7 (p. 314; Method I). The average duration of these cycles is almost exactly the same for wheat outputs and for volumes of crop production—3.21 years and 3.19 years respectively. These average durations of cycles are slightly longer than that determined for similar cycles in 25 regional series on wheat yields taken together, which is 3.10 years (p. 313).

We have already shown that the fluctuations in wheat yields do not differ significantly from fluctuations of random series. We know also that fluctuations in the 13 wheat production series, used in our present comparison, diverge more from random fluctuation than do those in the yields series, but that the principal cause of this divergence is the presence in the wheat production series of an important nonrandom component in the form of very pronounced trends (p. 308).

Under these circumstances, close similarity of cycles in wheat production and of cycles in the volume of crop production, as regards average duration and the distribution of durations of the cycles, may indicate that fluctuations in the volume of crop production do not

averages of the total outputs of the several crops included, which cover from one-half to two-thirds of the total crop production for most of the countries included in his study. As weights Brandau used the average prices (wholesale) of the respective crops for the base period 1910–14. His index numbers, accompanied by annual data on crop outputs and sources of these data, are given in the appendix tables of his study (*op. cit.*, pp. 70–104). For the United States, Brandau used the index of the volume of crop production constructed by V. P. Timoshenko, in *The Role of Agricultural Fluctuations in the Business Cycle* (Michigan Business Studies, Vol. 2, No. 9, Ann Arbor, Mich., 1930).

[73] These are series for which randomness of fluctuations have been tested in Section II of this study (p. 307). For their description, see Table II.

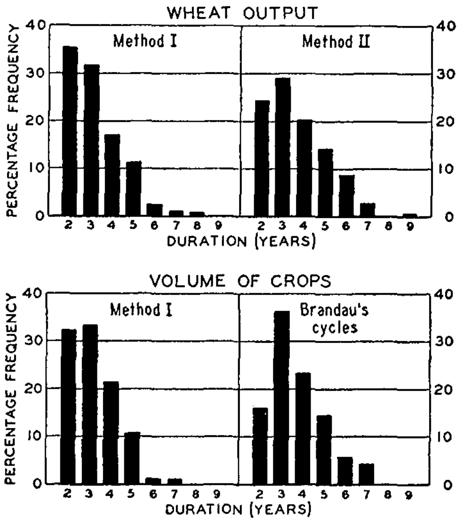
[74] The first type of cycles we identified in Brandau's index numbers. For the second type, cycles determined by Brandau himself were used. He measured their durations between consecutive troughs, after some minor fluctuations were omitted from counting as separate cycles. He did not explicitly state the basis for these omissions, but it appears to be comparable to that we have used. Frequency distributions of cycle durations determined by Brandau are given for each index number of the volume of crop production (*op. cit.*, p. 23).

[75] In absolute numbers, the frequencies are as follows:

Cycle durations (*years*)	Number of cycles			
	13 wheat output series		8 series on crop volumes	
	Method I	Method II	Method I	Brandau's
2	85	36	27	11
3	76	43	28	25
4	41	30	18	16
5	27	21	9	10
6	6	13	1	4
7	3	4	1	3
8	2	..	..	..
9	..	1	..	..
Total	240	148	84	69

diverge significantly from random fluctuations. Although 2-year cycles appear in slightly smaller proportion, and 4-year cycles appear in slightly larger proportion, in the volume of crop production than in the wheat outputs, this can hardly be regarded as a sufficient indication of a significant difference in the character of their fluctuations.

CHART 11.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN WHEAT OUTPUTS FOR 13 SELECTED AREAS COMBINED, AND IN THE VOLUME OF CROP PRODUCTION FOR 8 SELECTED COUNTRIES COMBINED*



* Data in footnote 75, p. 325.

Somewhat greater differences may be noted (Chart 11) between the distribution of cycle durations in wheat outputs as measured by Method II and the distribution of cycle durations established by Brandau in the fluctuation of the volumes of crop production, after he omitted some minor peaks and troughs. The principal difference is that the proportion of 2-year cycles in the Brandau series is substantially smaller and the proportion of 3-year cycles substantially larger than in the fluctuation of wheat outputs. But the procedure that we applied to the series in wheat outputs for elimination of minor movements and that used by Brandau are not identical. Brandau's procedure may involve more subjective judgment than the one we used in the case of wheat outputs.[76] However, the appearance in somewhat smaller proportion of 2-year cycles in the distribution of Brandau's cycles might be caused by the smaller proportion of these durations of cycles identified between every two peaks in the series on the volume of crop production, as noted earlier. In any event, these differences between the distributions of cycle durations in both types of cycles are too small to indicate a significant difference in the type of fluctuations in the volumes of crop production and in the wheat outputs.

Consequently, it may be concluded that if chance dominates fluctuations in yields and outputs of wheat, it also dominates fluctuations in the volumes of other crops. In order to make this conclusion more definite, it would be desirable to have index numbers of the volume of crop production of longer duration, covering larger numbers of regions, and constructed more uniformly as to number and kind of crops represented. But we doubt that analysis of more comprehensive index numbers of the volume of crop production would result in a materially different conclusion.

CYCLES IN WHEAT AND BUSINESS CYCLES

Another comparison is of interest here: between cycles in wheat yields and business cycles. The question here is not that of comparing the timing of these two kinds of cycles, which might raise questions as to their causal interrelations, but simply of comparing the average durations and the distributions of durations of cycles in wheat yields and in business fluctuations. The object is merely to see whether, and by how much, the average duration of cycles in wheat yields, as determined after the elimination of some minor fluctuations, differs from that of business cycles.

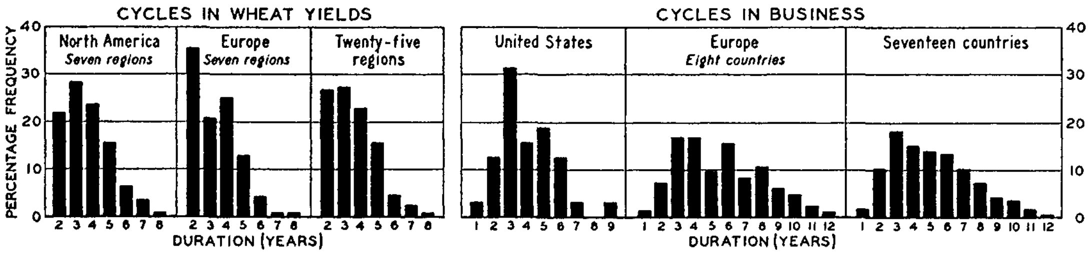
We shall use for our comparison the frequency distributions of business cycle durations approximated in years on the basis of business annals, as given in Wesley C. Mitchell's book on business cycles.[77] Business cycles in 17 countries—8 in Europe, and 9 in other continents—were identified on this basis, for

[76] We did not apply to our wheat production series the more laborious Method III of eliminating minor fluctuations, used for the 25 series on wheat yield.

[77] Mitchell, *op. cit.*

periods that vary greatly from one country to another—from more than a century for England and the United States to only slightly above 30 years for most other countries included. For the purpose of statistical analysis of duration of cycles, Professor Mitchell combined information on cycle durations for individual countries by various groups of countries. Distributions of business cycle durations for some of these groups may be conveniently compared with durations of cycles in wheat yields for groups of regions by geographical areas. The left side of Chart 12 fluctuations appears in Europe, where business cycles tend to be significantly longer than in the United States (their average duration is 5.6 years), while cycles in wheat yields are shorter in Europe than in North America. But the difference is large also when the average duration of cycles in wheat yields for all 25 selected regions is compared with that for business cycles in 17 countries. They are respectively 3.5 years and 5.2 years. Thus, the cycles in wheat yields are definitely shorter than the business cycles, except in North America.

CHART 12.—FREQUENCY DISTRIBUTIONS OF CYCLE DURATIONS IN WHEAT YIELDS AND IN BUSINESS FLUCTUATIONS FOR SELECTED REGIONS AND COUNTRIES*



* Data in Table III and in sources indicated in footnote 78.

shows the frequency distributions of cycle durations in wheat yields: (1) for 7 North American regions, (2) for 7 European regions, and (3) for all 25 regions included in the analysis of cycles in wheat yields. The right side of the same chart shows the frequency distributions of business cycle durations: (1) in the United States of America, (2) in 8 European countries, and (3) in all 17 countries for which business cycles were identified on the basis of their business annals.[78]

Comparison reveals various similarities and many differences. First, the average durations of cycles in wheat yields differ significantly from the average durations of business cycles, with one exception: cycles in wheat yields in North American regions (3.7 years) have nearly the same average duration as business cycles in the United States (about 4 years). The greatest difference in the average durations of cycles in wheat yields and in business

[78] For information on the frequency distribution of business cycles by durations for these groups of countries and others, see Mitchell, *op. cit.*, pp. 399–400.

A somewhat different situation exists when, instead of the average durations, the typical or most frequent durations of cycles are compared. The 3-year cycle is usually, with the exception of some regions mainly in Europe, the most frequent cycle in wheat yields (p. 319). We know that the 4-year cycle also appears frequently in the distributions of cycle durations in wheat yields as a primary or as a secondary mode. It appears clearly in European wheat yields. Cycles of 3 and 4 years appear most frequently also in the business fluctuations. Chart 12 shows that the 3-year cycle is particularly typical of American business fluctuations. Together with the 4-year cycle, it is also the most frequent in European business cycles. It is the most frequent also in cycles for all 17 countries taken together. Thus frequent appearance of 3- and 4-year cycles is characteristic both of wheat yields and of business. The difference between the two series of cycles in this respect is not in their typical duration, but in the fact that much longer cycles appear fairly frequently in business fluctuations while they are exceptional in yield fluctuations.

As a consequence of this, variations in duration are substantially greater for the business cycles than for the cycles in wheat yields. If we measure the degree of variation in percentage of the mean average duration of cycles, which seems appropriate because of the substantial differences in these average durations, the coefficient of variation for the duration of business cycles is 42 per cent for the United States, 45 per cent for the 8 European countries, and 47 per cent for all 17 countries taken together.[79] Corresponding coefficients for the variations in durations of cycles in wheat yields are 40 per cent for European regions, and 38 per cent for North American regions and for all 25 selected regions. Consequently, 3- and 4-year cycles are relatively more typical of fluctuations in wheat yields than of business fluctuations; they recur more frequently in yields than they do in business fluctuations. If so, and if the regularity in the recurrence of cycles of certain duration is essential in the definition of cycles, then 3½-year cycles in wheat yields may be called cycles with as much justification as the business cycles (see further p. 329).

Turning now to a comparison of the degree of regularity of the frequency distributions shown in Chart 12, we observe first that the distribution of cycle durations in wheat yields in 7 North American regions is much more smooth and regular than for business cycle durations in the United States. But this is to be expected because of the difference in the size of samples: the total number of cycles in wheat yields for 7 North American regions is 110, while only 32 business cycles were observed in the United States during the period 1796–1923. Also contributing to the regularity in the distribution of cycle durations for North American yields is the fact that regional yields of wheat in America fluctuate with a substantial degree of independence from region to region (p. 319).

The distributions of cycle durations in European wheat yields and business cycles show much less difference in degree of regularity. Both are relatively irregular, in spite of the fact that the samples are fairly large in both cases—116 cycles in European regional wheat yields, and 84 business cycles for the 8 European countries. Irregularities in both distributions may presumably be explained by the fact that there is a considerable degree of interdependence both between fluctuations in regional yields of wheat in Europe and between the business fluctuations in individual European countries. The first can be explained by similarity in weather fluctuations throughout many regions of western Europe; the second by various interconnections of the European national economies.

There is also a substantial degree of similarity between the distributions of cycle durations in wheat yields and in business cycles when the first are shown for 25 regions and the second for all 17 countries taken together. Both distributions are asymmetrical, but both show a substantial degree of regularity and smoothness. However, to use the words of Professor Mitchell, in characterizing the frequency distributions of durations of business cycles:

> The regularity which emerges, consists, not in the preponderance of cycles of any given duration, but in the way in which cycles of different durations group themselves about their central tendency. The distribution is of a type found in many studies of biological and social phenomena.[80]

With the exception that cycles in yields are concentrated more closely around their central tendency than are business cycles, both distributions may be regarded as of the same type and of the same degree of regularity. The regularity in the distribution of both kinds of cycles increases with the increase in the size of samples and in the independence of observations.[81] If the distribution of yield cycles for the 25 selected regions appears somewhat more regular than that for business cycles in 17 countries, this may be explained by the fact that 372 yield cycles are included in the first, and 166 business cycles in the second.

From the character of distributions of business cycles according to their durations, Professor Mitchell infers that

[79] Mitchell, *op. cit.*, pp. 402, 404.

[80] *Ibid.*, p. 418.

[81] *Ibid.*, p. 406.

. . . . like other biological and social phenomena whose distributions are well described by some form of the normal curve,[82] the durations of business cycles may be regarded as the net resultants of a multitude of factors which are largely independent of each other. If there is any dominant factor or set of factors, which tends to produce cycles of uniform duration, its influence is greatly modified by a host of other factors combined in ways which vary endlessly.[83]

This inference may likewise apply to cycles in wheat yields in spite of the fact that their durations vary within much narrower limits than those of business cycles. The mean average duration of yield cycles of 3½ years has some characteristics of a typical average, since cycles of 3- and 4-year durations represent central tendencies in most of the distributions of cycle durations in regional yields.

Paradoxically, furthermore, the greater variation in durations of business cycles, and the fairly frequent appearance of business cycles of long durations, may indicate that these cycles are dominated less by independent random factors than are fluctuations in yields. In a series of values dominated by independent random factors, long sequences of changes in the same direction appear very seldom, as we have seen (p. 302). The fairly frequent appearance of business cycles of long durations indicates rather that some of the factors influencing durations of business cycles are not independent among themselves, while the dearth of long cycles in fluctuations of wheat yields, even when minor movements are omitted, may point to their random character.

Summary of Conclusions

These few comparisons of cycles in yields and outputs of wheat with corresponding cycles in the volumes of crop production and with business cycles help us to summarize our conclusions in relation to the character of fluctuations in wheat yield and production.

First, fluctuations in regional yields of wheat, and presumably of most other crops, are dominated by many independent, fortuitous factors, among which random variations of weather from one season to another are perhaps of greatest importance. Chance presumably dominates not only fluctuations in yields from year to year in individual regions, but to a certain extent also variations in the sequence and magnitude of fluctuations in yields from one region to another. However, final conclusions on this last point must be postponed until correlations between fluctuations in regional yields have been studied.

Second, fluctuations in yields per acre tend for wheat and presumably for other crops to result in similar fluctuations in the total output. But in some instances rapid expansion (or contraction) of the crop area may result in a prolongation of the sequences of changes in the same direction in total output; and consequently, fluctuations in output tend to appear less clearly random than those in yields per acre.

Third, the lack of sensitivity of the Wallis-Moore test to certain kinds of cyclical fluctuations makes it impossible for us to conclude that long cycles in wheat yields, even strictly periodic ones, do not exist. The test shows only that cyclical changes in yields, if any, when measured between consecutive years, must be definitely smaller than year-to-year random fluctuations.

Fourth, cycles in wheat yields of 3½-years average duration, obtained by applying to annual data on wheat yields the usual analysis of time series into various component parts, have certain characteristics in common with cycles counted between successive peaks in the respective yield series. Their average durations vary from region to region in no definitely systematic way, and there is not much regularity in the recurrence of cycles of one particular duration. But in this respect they do not differ significantly from business cycles. On the contrary, 3- and 4-year cycles appear in yield fluctuations with greater relative frequency than in business cycles, though they represent central tendencies in both.

Fifth, comparisons of cycles in wheat outputs in the major wheat-export and -import areas with Brandau's cycles in the volumes of

[82] Mitchell (*op. cit.*, pp. 418–19) has found that a logarithmic normal curve fits fairly close to the distribution of business cycle durations for 17 countries shown in Chart 12 (p. 327).

[83] *Ibid.*, pp. 419–20.

crop production for various countries suggest that outputs of other crops fluctuate similarly to wheat production, and that cycles of 3- and 4-year durations are typical of these fluctuations also. Under such circumstances, it appears significant that cycles of these durations occur most frequently also in business cycles in various countries of the world, particularly in the United States, though they are less typical of business fluctuations than of yields.

Finally, the relatively frequent occurrence of cycles of much longer duration in business fluctuations points to a greater degree of interdependence between factors influencing durations of cycles in business than is characteristic of factors determining fluctuations in yields. Consequently, fluctuations in business appear to be less random in character than are fluctuations in yields. However, frequent appearance of cycle durations characteristic of phenomena dominated by random factors indicates that such factors play an important role also in the determination of durations of business cycles.

This research was made possible by a grant to the Food Research Institute from the Rockefeller Foundation. The author is indebted to M. K. Bennett for permission to use material from his files; to W. Allen Wallis for reading the manuscript of Section II; to Evelyn Wyant for tabulations and computations, made under the supervision of Pavel P. Egoroff; to P. Stanley King for the charts; and to Helen M. Gibbs for assistance with the manuscript.

APPENDIX NOTE

REGIONAL DIVISIONS AND SOURCES OF CROP DATA

Regions

In our study of variability in wheat yields, we have in general used the regional subdivisions of the wheat "world" adopted by Bennett in his earlier study of yields.[1] In this Note, however, the regions and subregions are defined as they are used in this study (of which only Part I is now presented), with indications of minor departures from those used in Bennett's study.

The only departure from Bennett's regional division of North America is in relation to the region he called Eastern North America. This included 17 eastern states of the United States, the Canadian province of Ontario, and four states of the Pacific Southwest. The region so defined appeared lacking in homogeneity for our purposes. We omitted Ontario province completely, and treated the four southern Pacific states as an additional region, though this area may be regarded as too small to be comparable with other major regions of North America. With these changes, the seven major wheat regions of North America, with subregions, are defined thus:

- Prairie Provinces, Canada, includes Manitoba, Saskatchewan, and Alberta. Before 1898 crop statistics for Manitoba alone are available, and these statistics were used to represent the region as a whole. Separate provinces are regarded as subregions in the study of some problems of variability in yields.
- United States Spring Wheat consists of two subregions: Minnesota and South Dakota, and North Dakota and Montana.
- Eastern United States consists of two subregions: *Northeastern*, including Maine, Vermont, New York, New Jersey, Pennsylvania, Maryland, and Delaware; *Southeastern*, including Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Arkansas.
- United States Soft Winter consists of two subregions: *Eastern*, including Michigan, Ohio, and Indiana; and *Western*, including Illinois, Wisconsin, Iowa, and Missouri.
- United States Hard Winter consists of three subregions: *Northeastern*, including Nebraska and the eastern half of Kansas; *Northwestern*, including the western half of Kansas, Colorado, and Wyoming; and *Southern*, including Texas, New Mexico, and Oklahoma.
- Pacific Northwest includes Washington, Oregon, and Idaho, which are regarded as subregions in the study of some of the problems of variability in yields.
- Pacific Southwest includes Utah, Nevada, Arizona, and California.

Departures from Bennett's regional divisions of Europe (including French North Africa) were necessary in cases in which crop statistics for considerable portions of the period covered by the study of trends (1885–1936) were regarded as unsatisfactory for the purpose of study of variability in yields. For this reason were omitted from analysis in this part of our study statistics relating to: (*a*) eastern subregion of Northern Europe, including Austria (postwar); Poland; the four Baltic states; Finland; and Bohemia, Moravia, and Silesia in Czechoslovakia; (*b*) the southern subregion of Southeastern Europe, including Bulgaria and Greece; (*c*) practically all countries composing the Western Mediterranean region with the exception of Algeria. With these changes the five major wheat regions of Europe, with their subdivisions into subregions, are defined as follows:

- Northern Europe consists of two subregions: *West*, including British Isles, Belgium, the Netherlands, and the three Scandinavian countries; and *Germany*.
- Southeastern Europe consists of two subregions: *West*, in which, for the period 1885–1918, are included prewar Hungary, Bosnia-Herzegovina, and Serbia; and, for the period from 1919, postwar Hungary, Jugoslavia, Transylvania, and Bucovina (parts of postwar Rumania), and Slovakia and Sub-Carpathian Russia (parts of Czechoslovakia); and *East*, including, for the period 1885–1918, prewar Rumania and Bessarabia; and, for the period from 1919, postwar Rumania excluding Transylvania and Bucovina.
- France consists of four subregions: *Northern*, *East Central*, *West Central*, and *Southern*.[2]
- Italy consists of two subregions: *Northern* and *Southern* Italy.[3]

[1] M. K. Bennett, "Trends of Yield in Major Wheat Regions since 1885, Parts I and II," Wheat Studies, November 1937, XIV, 69–102, March 1938, XIV, 263–318. The major wheat regions are defined on pp. 71–73, and subdivisions of the major regions into subregions are shown in various sections in which trends of regional wheat yields are discussed.

[2] In these four regions are included in the following way the eight regions specified in French official statistics: the Northern subregion includes *Nord;* East Central includes *Est* and *Est Central;* West Central includes *Centre* and *Ouest;* and the Southern subregion includes *Sudouest*, *Massif Central*, and *Midi*.

[3] In Southern Italy are included *Campania*, *Lazio*, *Abruzzi*, *Puglie*, *Lucania*, *Calabria* on the peninsula, and two islands *Sicilia* and *Sardinia*. Northern Italy includes the remaining northern portion of the peninsula.

WESTERN MEDITERRANEAN is represented in Part I of our study by Algeria alone, while in Bennett's study it includes Spain and Portugal in Europe, and Morocco, Algeria, and Tunis in French North Africa.

For the study of certain problems (see Table I), Europe is represented also by three areas which duplicate some portions of the regions above defined. Statistics of yield of wheat per acre for Prussia, Hungary, and Rumania are given for varying frontiers as changed by wars.

AUSTRALIA is represented in this study by the four principal wheat-producing states: *New South Wales, Victoria, South Australia,* and *Western Australia,* which are severally regarded as subregions. In Bennett's study, Victoria and South Australia were combined into one subregion.

INDIA consists of three subregions: *Northwest,* including Punjab, Delhi, and North-West Frontier Province; *Northeast,* including United Provinces, Bihar and Orissa, and Bengal; and *South,* including all other wheat-producing regions of India. No subregional data are used in this part of the study.

SOUTH AMERICA is represented in this study by *Argentina* alone. For study of some of the problems in variability in yields, the principal wheat regions of Argentina are grouped in two subregions: *Southern,* including Buenos Aires and La Pampa Territory; and *Northern,* including Entre Ríos, Santa Fé, and Córdoba. In Bennett's study South America was represented by Argentina and Uruguay.

The three major wheat regions of European Russia included in this study are defined in such a way that they group smaller regions (provinces) with similar fluctuations in wheat yields.[4] It was necessary to take Russian regions of relatively large size, because the shift of frontiers of the crop reporting regions in the postrevolutionary period precluded the preservation of the identity of regions of smaller areas. Consequently, Russian regions are not homogeneous in certain respects, particularly the degree of variability in yields. This relates particularly to Ukraine, which should be divided into at least two natural subregions: the southern prairie area, and the northern wooded prairie area.

UKRAINE, for the period 1883–1917, includes the following eight provinces: Podolia, Kiev, Kherson, Chernigov, Poltava, Kharkov, Ekaterinoslav, and Taurida. The territory of these provinces roughly corresponds to the territory of the Ukraine SSR taken together with the Crimea for the postrevolutionary period.

NORTH CAUCASUS, for the period 1892–1917, includes three provinces: Kuban, Stavropol, and Terek. For the postrevolutionary period, the North Caucasus covers usually a somewhat larger area, since its administrative frontiers include a large portion of the old province of the Don Cossacks.

VOLGA REGION, for the period 1883–1917, includes the following ten provinces: Astrakhan, Saratov, Samara, Orenburg, Penza, Simbirsk, Kazan, Viatka, Ufa, and Perm. For the postrevolutionary period, it was possible to preserve the identity of the above defined region only very roughly, because of repeated shifts in administrative frontiers. For 1928–1934 the Volga region was represented by the following crop-reporting regions: Lower Volga, Middle Volga, Tartar and Bashkir SSR, and the Ural province.[5]

These three regions cover the principal wheat-producing area of European Russia, except (for the prerevolutionary period) the province of the Don Cossacks, which in the postrevolutionary period is divided among the three regions defined above. For the first two regions, winter and spring wheat are shown separately, while in the Volga region winter wheat is omitted because of its negligible area.

Regions used in the analysis of the total production of wheat (Table II) do not need particular definition, since they represent principal exporting and importing countries, with three exceptions: Northern Europe, West, which corresponds to the subregion of the same name used in the analysis of yield of wheat per acre; Southeastern Europe, which corresponds to the region of the same name used in the analysis of yield, with the addition of Bulgaria; and French North Africa, which includes Algeria and Tunis.

SOURCES OF CROP DATA

Statistical data on wheat yields per acre used in our study of variability in yields are, as far as possible, the same as those used by Bennett in "Trends of Yield." But additional data were necessary because of some departures in the definition of regions, as explained previously, and the extension backward and forward of the period covered by this study as compared with Bennett's uniform period, 1885–1936. These extensions and modifications were made by using the same or comparable sources of crop statistics. In all cases, wheat yields per acre used in this study are calculated from total production

[4] This grouping was made on the basis of a special study "Crop Fluctuations as Factors Influencing Stability of Russian Agriculture," by N. S. Tschetverikoff, in *Symposium of Essays on Statistics in Memory of N. A. Kablukov* [in Russian] (Moscow, 1925). On the basis of correlations between provincial yields of rye and oats, Tschetverikoff has grouped provinces in regions with similar fluctuations in yields. See his table, p. 119, and cartogram, p. 136.

[5] See WHEAT STUDIES, April 1937, XIII, 370–71.

for the respective regions or subregions divided by total acreage in the same areas.

For regions defined as separate countries or as groups of countries, crop statistics for the period 1885–1932 were taken from M. K. Bennett, "World Wheat Crops, 1885–1932" (WHEAT STUDIES, April 1933, IX, 265–74).[6] For years since 1932 these crop statistics were drawn from the "Review of the Crop Year," published each December in WHEAT STUDIES, mainly from Volume XVII, 1940. Crop statistics for European countries preceding 1885 were taken, with the exceptions next explained, from the *Annuaire Statistique de la France* (1938), where crop statistics are compiled from the official sources.

Crop statistics for the British Isles are, for 1875–1883, Lawes and Gilbert's estimates as given in *Report of the Committee on Stabilization of Agricultural Prices* (Ministry of Agriculture and Fisheries, Economic Series 2, 1925); and for 1884, from Board of Agriculture, *Agricultural Produce Statistics of Great Britain . . . . , 1891* (C. 6617, 1892). Data on yield of wheat per acre for Prussia are, for 1846–1913, from *Vierteljahrshefte zur Konjunkturforschung* (Sonderheft 35, 1934), p. 58; for 1914–1937, from *Statistisches Jahrbuch für das Deutsche Reich* for various years. Data on yield of wheat per acre for France for 1815–1874 are from *Journal de la Société de Statistique de Paris*, January 1936, p. 50. Subregional series on wheat yields for France and Italy, as well as crop statistics for the administrative regions of Czechoslovakia and postwar Rumania used in compilation of subregional series of Southeastern Europe, were compiled from the official crop statistics of the respective countries.

Data on yields of wheat per acre for the Prairie Provinces of Canada are, for 1885–1919, from WHEAT STUDIES, July 1925, I, 280–81; for 1920–39, from the Dominion Bureau of Statistics, *Monthly Bulletin of Agricultural Statistics*, various issues.

Regional and subregional series on yield of wheat per acre for the United States, with the exception of yield of wheat per acre on sown acreage in Kansas, are compiled from the U.S. Dept. Agr., *Revised Estimates of Wheat Acreage, Yield, and Production, 1866–1934* (September 1934, revised May 1937), and for subsequent years from U.S. Dept. Agr., *Crops and Markets*, various issues. In regions where yield on sown acreage was used, these data were compiled as follows: 1901–09, harvested acreage from *ibid.*, adjusted to approximate acreage sown by reference to percentages of winter wheat acreage abandoned, as given in U.S. Dept. Agr., *Wheat and Rye Statistics* (Stat. Bull. 12, January 1926), p. 12; 1909–19, *ibid.*, winter wheat sown plus spring wheat harvested; from 1919, area sown, *ibid.* Yields on sown acreage for the state of Kansas, 1885–1938, are from various issues of *Biennial Report of Kansas State Board of Agriculture.*[7]

Australian crop statistics by states are from the Commonwealth Bureau of Census and Statistics, *Production Bulletin, 1937–38:* Part II, *Primary Industries and Total Recorded Production* (No. 32, 1939); and for recent years from *Monthly Summary of the Wheat Situation in Australia,* various issues.

Subregional series on wheat yields in India are, for 1891–1925, from WHEAT STUDIES, July 1927, III, 398–99; from 1926 on, from Department of Commercial Intelligence and Statistics, *Estimates of Area and Yield of Principal Crops in India,* for various years.

Russian regional series on wheat yields for 1883–1915 are compiled from Central Statistical Administration of USSR, *Svod urozhainykh svedenii za gody, 1883–1915* [*Collection of Crop Statistics, 1883–1915*] (1928). In this publication are compiled by provinces statistics on production, acreage, and yields of principal crops on peasant lands, as reported by the Central Statistical Committee of Russia.

Data for 1916–24 are compiled from various publications of the Central Statistical Administration of the USSR: for 1916, 1917, 1920–22 from the *Collection of Statistical Information for the USSR, 1918–1923* (1924); for 1918 and 1919, from the *Statistical Yearbook for 1918–1920;*[8] for 1923 from the *Statistical Yearbook for 1922–1923;* and for 1924, from the *Statistical Yearbook for 1924.*

Data compiled from official sources for 1925–27 are from V. P. Timoshenko, *Agricultural Russia and the Wheat Problem* (Food Research Institute, Grain Economics Series 1, Stanford University, Calif., 1932), Tables VIII, IX, and X, pp. 534–45; and for 1928–34 from WHEAT STUDIES, April 1939, XIII, Table I, pp. 369–73.

Data on total production of wheat for the principal importing and exporting countries included in Table II are compiled from the sources indicated above. It is necessary to specify, however, that data on total production of wheat in Canada are from the Dominion Bureau of Statistics, *Monthly Bulletin of Agricultural Statistics*, September 1940, XXXIII, 301, and the total production of wheat in the USSR is taken as adjusted by M. K. Bennett in "World Wheat Crops, 1885–1932," p. 265.

[6] See pp. 260–62 for sources of data.

[7] Acreage and production for the western half of the state were secured by the addition of the acreage and production of the counties falling within that region. The same data for the eastern half of the state were secured by subtracting from the state total (according to the U.S. Department of Agriculture revised estimates) the data for the western half.

[8] Only yields per *desiatina* were reported for 1918 and 1919. No information on acreage was reported. These were interpolated on the basis of acreage for 1917 and 1920.

APPENDIX TABLES

TABLE I.—MEAN AVERAGE DURATION OF PHASES, AND NUMBER OF PHASES OF VARIOUS DURATIONS, IN SERIES OF WHEAT YIELD PER ACRE FOR SELECTED REGIONS AND SUBREGIONS, AND PROBABILITIES OF THE RANDOMNESS OF THE DISTRIBUTION OF COMBINED PHASES BY LENGTH

Region	Period	Mean average duration of phases				Duration of combined phases, in years, adjusted for ties[a]			Probability of randomness
		Expansion	Contraction	Combined	Combined adjusted for ties[a]	1	2	3 or more	
						Number of phases			
Prairie Provinces, Canada	1885–1939	1.47	1.53	1.50	1.50	20.50	11.00	2.50	.80–.70
United States Spring Wheat[b]	1866–1939	1.32	1.65	1.49	1.47	27.25	17.25	2.00	.30–.20
Eastern United States	1866–1939	1.70	1.35	1.52	1.49	29.00	14.50	3.50	.90–.80
Northeastern subregion	1866–1939	1.62	1.25	1.44	1.43	32.50	11.50	4.00	.90–.80
Southeastern subregion	1866–1939	1.67	1.25	1.46	1.40	34.00	14.00	2.00	.50–.30
United States Soft Winter	1866–1939	1.71	1.46	1.58	1.54	25.50	13.00	5.50	.80–.70
United States Soft Winter[b]	1866–1939	1.67	1.50	1.58	1.58	22.00	17.00	4.00	.30–.20
Eastern subregion	1866–1939	1.65	1.85	1.75	1.75	18.00	15.00	7.00	.10–.05
Eastern subregion[b]	1866–1939	1.54	1.64	1.59	1.59	23.00	17.00	4.00	.30–.20
Western subregion	1866–1939	1.50	1.36	1.43	1.43	34.00	9.00	6.00	.50–.30
United States Hard Winter[b]	1866–1939	1.59	1.67	1.63	1.59	24.00	14.50	5.50	.70–.50
Northeastern subregion[b]	1885–1938	2.00	1.40	1.70	1.70	15.00	11.00	4.00	.50–.30
Northwestern subregion[b]	1885–1938	1.73	1.44	1.58	1.56	20.00	8.00	4.00	.90–.80
Pacific Northwest	1869–1939	1.48	1.76	1.62	1.58	24.00	14.00	5.00	.70–.50
Pacific Southwest	1866–1939	1.29	1.70	1.49	1.49	30.00	12.00	5.00	.98–.95
Northern Europe, West	1875–1939	1.74	1.42	1.58	1.58	23.50	8.50	6.00	.50–.30
British Isles, Low Countries	1875–1939	1.89	1.44	1.67	1.62	22.50	8.00	6.50	.30–.20
Scandinavia	1875–1939	1.74	1.56	1.65	1.60	23.50	9.00	5.50	.70–.50
Germany	1878–1939	1.44	1.18	1.31	1.31	34.00	9.00	2.00	.20–.10
Prussia	1846–1937	1.52	1.50	1.51	1.48	40.00	15.00	5.00	.90–.80
Southeastern Europe, West	1885–1937	1.26	1.44	1.35	1.32	27.00	10.50	1.50	.30–.20
Southeastern Europe, East	1885–1938	1.73	1.47	1.60	1.60	16.00	10.00	4.00	.70–.50
Hungary	1885–1939	1.25	1.42	1.33	1.33	28.00	10.00	1.00	.30–.20
Rumania	1885–1939	2.00	1.57	1.79	1.79	14.00	8.00	7.00	.05–.02
France	1815–1939	1.46	1.59	1.53	1.53	48.50	20.00	9.50	.80–.70
Italy	1885–1939	1.37	1.32	1.34	1.34	26.00	11.00	1.00	.50–.30
Algeria	1875–1939	1.42	1.65	1.54	1.54	25.00	8.00	6.00	.50–.30
All Australia	1860–1939	1.42	1.71	1.56	1.56	28.00	15.00	5.00	.80–.70
New South Wales	1860–1939	1.64	1.35	1.49	1.49	30.00	17.00	4.00	.70–.50
South Australia	1860–1939	1.40	1.68	1.54	1.54	29.00	15.00	6.00	.80–.70
Western Australia	1868–1939	1.55	1.76	1.66	1.66	20.50	17.00	3.50	.20–.10
Victoria	1860–1939	1.74	1.61	1.67	1.67	24.00	13.00	9.00	.20–.10
India	1885–1939	1.59	1.50	1.54	1.50	20.00	11.50	2.50	.80–.70
Argentina[b]	1885–1939	1.69	1.56	1.62	1.62	18.00	8.00	6.00	.30–.20
Ukraine (winter wheat)	1883–1934	1.71	1.71	1.71	1.67	13.50	12.50	3.00	.20–.10
Ukraine (spring wheat)	1883–1934	1.80	1.47	1.63	1.63	18.00	6.00	6.00	.20–.10
Volga (spring wheat)	1883–1934	1.67	1.38	1.52	1.52	19.00	8.00	4.00	.90–.80
North Caucasus (winter wheat)	1892–1934	1.50	1.67	1.58	1.58	13.00	9.00	2.00	.70–.50
North Caucasus (spring wheat)	1892–1934	1.54	2.09	1.82	1.74	12.00	6.50	4.50	.30–.20

[a] See footnote 36, pp. 303–04.

[b] Wheat yield per acre computed on sown-acreage basis.

TABLE II.—MEAN AVERAGE DURATION OF PHASES, AND NUMBER OF PHASES OF VARIOUS DURATIONS, IN SERIES OF WHEAT PRODUCTION FOR SELECTED REGIONS, AND PROBABILITIES OF THE RANDOMNESS OF THE DISTRIBUTION OF COMBINED PHASES BY LENGTH

Region	Period	Mean average duration of phases				Duration of combined phases, in years, adjusted for ties[a]			Probability of randomness
		Expansion	Contraction	Combined	Combined adjusted for ties[a]	1	2	3 or more	
						Number of phases			
Importers									
Northern Europe, West	1875–1939	1.47	1.68	1.58	1.58	22.0	10.0	6.0	.50–.30
Germany	1878–1939	1.60	1.25	1.42	1.42	30.0	6.0	4.0	.30–.20
France	1815–1939	1.53	1.60	1.57	1.57	45.0	22.0	9.0	.80–.70
Italy	1885–1939	1.42	1.26	1.34	1.34	26.0	11.0	1.0	.50–.30
Spain	1885–1939	1.64	2.07	1.86	1.86	15.0	6.0	7.0	.05–.02
Exporters									
United States	1866–1939	1.90	1.55	1.72	1.72	20.0	14.0	6.0	.30–.20
Canada	1885–1939	1.87	1.53	1.70	1.70	15.0	12.0	3.0	.30–.20
Argentina	1885–1939	2.07	1.64	1.86	1.86	13.5	7.5	7.0	.05–.02
Australia	1860–1939	1.74	1.52	1.63	1.63	24.0	16.5	6.0	.50–.30
India	1885–1939	1.35	1.75	1.54	1.54	20.0	9.0	4.0	.90–.80
Southeastern Europe	1885–1937	1.53	1.50	1.52	1.52	21.0	8.0	4.0	.90–.80
French North Africa	1885–1939	1.17	1.63	1.40	1.40	24.0	11.0	2.0	.70–.50
USSR	1885–1938	2.08	2.00	2.04	2.04	11.0	7.0	7.0	.02–.01

[a] See footnote 36, pp. 303–04.

TABLE III.—AVERAGE DURATION AND NUMBER OF CYCLES OF VARIOUS DURATIONS IN WHEAT YIELD PER ACRE FOR 25 SELECTED REGIONS

(Average duration, in years, of cycles derived by three methods; number of cycles derived by Method III)

Region	Period	Average duration			Duration of cycles in years							Total number of cycles
		Method I[a]	Method II[b]	Method III[c]	2	3	4	5	6	7	8	
					Number of cycles							
Prairie Provinces, Canada	1885–1939	3.00	3.67	3.73	3	3	2	2	0	0	1	11
United States Spring Wheat'	1866–1939	3.00	3.71	3.50	3	8	4	2	0	1	0	18
Eastern United States	1866–1939	3.04	3.47	4.00	2	4	5	1	2	1	0	15
United States Soft Winter'	1866–1939	3.19	3.47	3.59	4	4	4	5	0	0	0	17
United States Hard Winter'	1866–1939	3.24	4.07	4.13	3	3	3	2	3	1	0	15
Pacific Northwest	1869–1939	3.24	3.62	3.62	5	2	5	2	2	0	0	16
Pacific Southwest	1866–1939	3.00	3.44	3.50	4	7	3	3	0	1	0	18
7 American series	....	3.10	3.62	3.71	24	31	26	17	7	4	1	110
Northern Europe, West	1875–1939	3.16	3.27	3.38	5	4	4	2	1	0	0	16
Germany	1878–1939	2.64	3.64	3.64	4	2	4	3	1	0	0	14
Southeastern Europe, West	1885–1937	2.72	3.07	2.92	6	3	3	1	0	0	0	13
Southeastern Europe, East	1885–1938	3.21	3.64	3.73	2	5	1	2	0	0	1	11
France	1815–1939	3.05	3.48	3.67	8	4	11	5	1	1	0	30
Italy	1885–1939	2.68	2.65	2.62	9	4	3	0	0	0	0	16
Algeria	1875–1939	3.05	3.38	3.38	7	2	3	2	2	0	0	16
7 European series	....	2.93	3.31	3.36	41	24	29	15	5	1	1	116
New South Wales	1860–1939	3.00	3.24	3.45	5	8	3	3	0	0	1	20
South Australia	1860–1939	3.08	3.82	3.45	6	7	1	4	2	0	0	20
Western Australia	1868–1939	3.35	3.35	4.07	1	4	3	5	1	0	0	14
Victoria	1860–1939	3.41	3.89	3.88	2	6	5	2	0	2	0	17
4 Australian series	....	3.20	3.56	3.68	14	25	12	14	3	2	1	71

[a] I: duration of cycles measured from peak to peak on original yield series.

[b] II: duration of cycles measured by number of years between up-crossings or down-crossings (whichever occurred first) of the line representing annual data with the line of trend.

[c] III: duration of cycles measured from peak to peak or from trough to trough (whichever occurred first) in deviations of annual yields from the line of trend; minor movements were omitted; see p. 311.

TABLE III (*Concluded*)

Region	Period	Average duration			Duration of cycles in years							Total number of cycles
		Method I[a]	Method II[b]	Method III[c]	2	3	4	5	6	7	8	
					Number of cycles							
India	1885–1939	3.12	3.23	3.23	4	5	1	3	0	0	0	13
Argentina[g]	1885–1939	3.25	3.90	3.54	3	2	4	1	1	0	0	11
20 series	....	3.07	3.49	3.55	86	87	72	50	16	7	3	321
Ukraine (winter wheat)	1883–1934	3.43	4.33	3.80	1	3	5	0	0	1	0	10
Ukraine (spring wheat)	1883–1934	3.27	3.90	3.73	3	2	2	3	1	0	0	11
Volga (spring wheat)	1883–1934	3.07	3.42	3.25	4	2	5	1	0	0	0	12
North Caucasus (winter wheat)	1892–1934	3.18	3.56	3.56	2	4	1	1	0	1	0	9
North Caucasus (spring wheat)	1892–1934	3.64	3.75	3.33	3	3	0	3	0	0	0	9
5 Russian series	....	3.30	3.77	3.53	13	14	13	8	1	2	0	51
25 series	....	3.10	3.52	3.55	99	101	85	58	17	9	3	372

[g] Wheat yield per acre computed on sown-acreage basis.

TABLE IV.—MEASURES OF AMPLITUDE OF CYCLES IN WHEAT YIELD FOR 25 SELECTED REGIONS

(*Bushels per acre*)

Region	Period	Mean av. yield	Standard deviation[a]	Average[b]		Maximum		Cycles derived by Method III[c]					
								Average[d]		Average[e]		Maximum	
				Peak	Trough	Peak	Trough	Peak	Trough	Rise	Fall	Rise	Fall
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Pr. Prov., Canada	1885–1939	16.8	4.19	4.01	3.79	9.9	8.6	4.71	4.22	8.66	9.18	15.8	16.7
U.S. Spring Wheat[f]	1866–1939	12.3	2.44	2.40	2.37	5.6	5.0	2.96	2.73	5.42	5.91	7.6	9.7
Eastern U.S.	1866–1939	12.8	1.36	1.29	1.19	5.0	3.0	1.51	1.29	2.77	2.62	6.5	8.0
U.S. Soft Winter[f]	1866–1939	14.5	2.66	2.32	2.54	8.0	8.2	2.60	2.89	5.56	5.35	17.0	11.5
U.S. Hard Winter[f]	1866–1939	12.0	2.61	2.14	2.43	6.0	5.3	2.78	2.79	5.53	5.95	9.1	10.9
Pacific Northwest	1869–1939	19.6	1.88	1.64	1.65	5.2	4.7	2.01	1.96	4.07	3.88	9.2	9.5
Pacific Southwest	1866–1939	16.1	1.74	1.64	1.80	3.4	4.6	1.92	2.14	4.09	3.85	8.0	6.4
N. Europe, West	1875–1939	32.1	2.30	1.93	2.05	5.4	4.6	2.02	2.19	4.72	3.79	9.1	6.0
Germany	1878–1939	25.9	2.01	1.88	2.08	4.2	5.5	2.19	2.27	4.85	3.96	8.0	9.1
S.E. Europe, West	1885–1937	16.9	2.19	1.62	1.97	4.4	4.8	1.81	2.44	4.08	4.25	6.6	9.4
S.E. Europe, East	1885–1938	13.5	3.61	3.18	3.93	5.4	8.5	3.78	4.19	7.98	8.36	12.9	12.8
France	1815–1939	17.1	2.10	1.84	2.06	5.1	5.1	2.23	2.43	4.80	4.42	9.6	8.8
Italy	1885–1939	16.2	1.83	1.69	1.90	3.2	4.2	1.69	1.90	3.79	3.38	6.2	6.4
Algeria	1875–1939	8.2	1.43	1.44	1.39	4.0	3.3	1.53	1.59	3.18	2.99	6.5	6.7
New South Wales	1860–1939	12.0	3.13	2.75	2.76	7.6	8.6	3.16	3.24	6.33	6.10	16.3	12.9
South Australia	1860–1939	8.8	2.35	2.50	2.32	6.3	8.6	2.58	2.44	4.92	4.92	15.1	9.6
Western Australia	1868–1939	10.6	2.11	1.44	1.66	3.2	7.0	1.99	2.08	3.98	3.94	8.6	10.3
Victoria	1860–1939	12.2	2.94	2.53	2.90	5.8	10.5	2.88	3.58	5.99	6.31	15.0	11.4
India	1885–1939	10.6	.88	.78	.93	1.8	1.9	.80	1.01	1.92	1.78	3.3	2.9
Argentina[f]	1885–1939	11.2	2.40	2.45	2.28	6.5	5.7	2.60	2.48	4.89	4.96	8.2	13.0
Ukr. (winter wheat)	1883–1934	11.8	2.89	2.45	2.75	6.6	5.1	2.96	3.10	6.19	5.96	9.9	11.4
Ukr. (spring wheat)	1883–1934	8.1	1.96	2.18	1.63	4.2	3.7	2.37	2.01	4.43	4.13	7.8	6.0
Volga (spring wheat)	1883–1934	7.3	2.40	2.76	2.24	4.1	6.1	2.76	2.24	5.24	4.80	9.5	9.0
N. Cauc. (winter wh.)	1892–1934	11.0	2.27	2.15	2.37	4.4	5.4	2.36	2.57	5.07	4.66	9.9	6.9
N. Cauc. (spring wh.)	1892–1934	9.4	2.13	2.24	2.16	6.4	4.0	2.41	2.43	4.76	4.49	9.1	8.1

[a] Standard deviation of all differences between annual yields and ordinates of the line of trend for the respective years.

[b] The years of peaks and of troughs are determined for deviations of yield from the line of trend. The magnitudes of the peaks and of the troughs are the absolute differences between the yield in each respective year and the ordinate of the line of trend for the same year. The mean averages of all peaks and of all troughs are given.

[c] See footnote *c*, Table III.

[d] Mean average of peaks and of troughs, as explained in footnote *b*, except that minor movements were omitted.

[e] The rise from a trough to the following peak, or the fall from a peak to the following trough, is the absolute difference between the yields in the two respective years. The years of peaks and of troughs were determined by Method III. The mean averages of all rises and of all falls, for each series, are given.

[f] Wheat yield per acre computed on sown-acreage basis.

TABLE V.—MEASURES OF AMPLITUDE OF CYCLES IN WHEAT YIELD FOR 25 SELECTED REGIONS

(Percentages of mean average yield, except as noted)[*]

Region	Period	Mean av. yield bu. per acre	Coefficient of variability[a]	Average[b]		Maximum		Cycles derived by Method III[c]					
								Average[d]		Average[e]		Maximum	
				Peak	Trough	Peak	Trough	Peak	Trough	Rise	Fall	Rise	Fall
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Pr. Prov., Canada...	1885-1939	16.8	24.9	23.9	22.5	58.9	51.2	28.0	25.1	51.6	54.7	94.0	99.4
U.S. Spring Wheat[f]..	1866-1939	12.3	19.8	19.5	19.3	45.5	40.7	24.0	22.2	44.0	48.1	61.8	78.9
Eastern U.S.	1866-1939	12.8	10.6	10.1	9.3	39.1	23.4	11.8	10.1	21.7	20.5	50.8	62.5
U.S. Soft Winter[f]....	1866-1939	14.5	18.3	16.0	17.6	55.2	56.5	17.9	20.0	38.3	36.9	117.2	79.3
U.S. Hard Winter[f]...	1866-1939	12.0	21.7	17.8	20.2	50.0	44.2	23.2	23.3	46.1	49.6	75.8	90.8
Pacific Northwest...	1869-1939	19.6	9.6	8.4	8.4	26.5	24.0	10.2	10.0	20.8	19.8	46.9	48.5
Pacific Southwest...	1866-1939	16.1	10.8	10.2	11.2	21.1	28.6	12.0	13.3	25.4	23.9	49.7	39.8
N. Europe, West.....	1875-1939	32.1	7.2	6.0	6.4	16.8	14.3	6.3	6.8	14.7	11.8	28.3	18.7
Germany	1878-1939	25.9	7.8	7.3	8.0	16.2	21.2	8.5	8.8	18.7	15.3	30.9	35.1
S.E. Europe, West...	1885-1937	16.9	13.0	9.6	11.7	26.0	28.5	10.7	14.5	24.2	25.1	39.1	55.6
S.E. Europe, East....	1885-1938	13.5	26.7	23.5	29.1	40.0	63.0	28.0	31.1	59.1	61.9	95.6	94.8
France	1815-1939	17.1	12.3	10.8	12.0	29.8	29.8	13.0	14.2	28.1	25.8	56.1	51.5
Italy	1885-1939	16.2	11.3	10.5	11.7	19.8	25.9	10.5	11.7	23.4	20.8	38.3	39.5
Algeria	1875-1939	8.2	17.4	17.5	18.6	48.8	40.2	17.0	19.4	38.7	36.4	79.3	81.7
New South Wales....	1860-1939	12.0	26.1	22.9	23.0	63.2	71.7	26.3	27.0	52.8	50.9	135.8	107.5
South Australia	1860-1939	8.8	26.7	28.4	26.3	71.6	97.7	29.3	27.8	55.9	56.0	171.6	109.1
Western Australia...	1868-1939	10.6	19.9	13.6	15.6	30.2	66.0	18.7	19.7	37.5	37.2	81.1	97.2
Victoria	1860-1939	12.2	24.1	20.8	23.7	47.5	86.1	23.6	29.4	49.1	51.7	123.0	93.4
India	1885-1939	10.6	8.3	7.4	8.7	17.0	18.0	7.5	9.5	18.1	16.8	31.1	27.4
Argentina[f]	1885-1939	11.2	21.4	21.8	20.3	58.0	50.9	23.2	22.1	43.7	44.2	73.2	116.1
Ukr. (winter wheat).	1883-1934	11.8	24.5	20.8	23.3	55.9	43.2	25.1	26.3	52.5	50.5	83.9	96.6
Ukr. (spring wheat).	1883-1934	8.1	24.2	26.9	20.1	51.9	45.7	29.2	24.8	54.7	51.0	96.3	74.1
Volga (spring wheat)	1883-1934	7.3	32.9	37.8	30.7	56.2	83.6	37.8	30.7	71.8	65.8	130.1	123.3
N. Cauc. (winter wh.)	1892-1934	11.0	20.6	19.5	21.6	40.0	49.1	21.4	23.4	46.1	42.3	90.0	62.7
N. Cauc. (spring wh.)	1892-1934	9.4	22.7	23.8	22.9	68.1	42.6	25.6	25.9	50.6	47.8	96.8	86.2

[*] Values of various measures of amplitude, as given in bushels per acre in the respective columns of Table IV, are here presented as percentages of the mean average yield computed for the entire duration of each series.

[a] Standard deviation expressed as a percentage of the mean average yield; see footnote *a*, Table IV.

[b], [c], [d], [e], [f] See corresponding footnotes in Table IV.

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