C. W. J. GRANGER (in association with M. HATANAKA). *Spectral Analysis of Economic Time Series*, Princeton University Press, 1964. $8.50. xviii + 300 pp.

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The book has a misleading title, since its scope is *nonparametric* spectral analysis. In the area of time series analysis so defined the book has broad coverage, giving a many-faceted exposition of modern spectral techniques, with rich graphic illustrations, and with comments oriented toward "empiricism without theory" rather than toward the testing of fullfledged hypothetical models. Spectral analysis for purposes of parametric model building is toned down or suppressed. Since parametric vs. nonparametric approaches are competitive rather than complementary, the restriction of the scope of the book is a severe one, and if it were to upset the existing balance of the two lines of approach it would set back the clock of econometrics by some 35 years.

The following comments serve to substantiate the above brief appraisal. But first of all the list of contents:

Chapter headings: 1. Introduction to the analysis of time series; 2. Nature of economic time series: Part A. *Stationary time series*; 3. Spectral theory; 4. Spectral analysis of economic data; 5. Cross-spectral analysis; 6. Cross-spectral analysis of economic data; 7. Processes involving feedback: Part B. *Nonstationary time series*; 8. Series with trending means; 9. Series with spectrum changing with time; 10. Demodulation; 11. Non-stationarity and economic series; 12. Application of cross-spectral analysis and complex demodulation: Business cycle indicators (by M. Hatanaka); 13. Application of partial cross-spectral analysis: Tests of acceleration principle for inventory cycle (by M. Hatanaka); 14. Problems remaining; Index.

1. Speaking broadly, spectral analysis comes to the fore when the observed time series are long, relative to the periods or waves under consideration. This is so, for example, in the study of ocean waves, where under specified wind conditions the number of waves runs into hundreds and thousands. Similarly in the filtering of radio signals, radar detection problems, and so on.

With a large number of periods, waves, it is often illuminating and more convenient to work in the *frequency domain* of the spectrum than in the *time domain* of the observed data (the frequency is inversely proportional to the length of a period). But with a small number of periods it is more or less artificial to emphasize the frequency domain, especially if the periods are irregular in length and/or amplitude, as is the case in economic applications.

The requisite of a relatively large number of periods, waves, to be covered by the data for spectral analysis to be fruitful is not adequately emphasized by the authors. Econometricians, both advanced and less advanced ones, must ask what is gained by a spectrum where it is only all too clear that many features are the outcome of randomness in the phenomena under analysis, and the observations cover a period too short to tone down these features.

2. The methods of time series analysis may be classified under two broad headings:

(a) Nonparametric approaches;

(b) Parametric approaches.

The dichotomy (a)–(b) is largely a division of labour. Non-parametric models and methods of analysis are to the point in descriptive and other low-information approaches, the typical situation being either

(i) we do not *have* the requisite information to build parametric models, or

(ii) we do not *want* to squeeze the data for all potential information, be it that data are available in abundance, or that for some reason or other we are primarily interested in a low-information model.

As to (i), this is often the situation in an early phase of scientific penetration, when the emphasis is on exploratory investigations, retrospective and descriptive, and the formation of an explanatory theory is tentative and its beginnings. Parametric approaches often represent a later phase of evolution, when an explanatory theory is more firmly established and has reached the stage of parametric models that can be projected into the future and thereby subjected to predictive testing.

As to (ii), a typical case in point is that the tempo is essential—radar detection of aircraft attacks, for example—so that the time-consuming techniques of high-information parametric models are pushed aside for "quick-and-dirty" methods that with minimum delay can detect the characteristic wave signals against the background noise.

Hence it can be said that parametric approaches are intermediate between (i) and (ii), the situation being such that all available information has to be exploited for the problems at issue. Now economic and econometric analysis in the present stage of evolution, quite evidently, is intermediate between (i) and (ii). It will suffice to remind that the prediction problems of the boom-recession pulsations are as yet far from being mastered, so in the construction of econometric forecasting models it is certainly at a premium to take well care of every bit of information. Hence when statistical techniques designed for situations (i) or (ii) are applied to economic data, and this is Granger-Hatanaka's program, it can be expected that the result will be the same as when sitting down between two chairs. The net outcome of their applied work, as we shall see, comes close to this brief description.

3. Under each heading (a)–(b) there is a general representation theorem. Under (a) we have *Cramér's representation* (1940),

$$(A_1) \qquad y_t - E(y_t) = (2/n)^{\frac{1}{2}} \int_0^{\pi} [\cos \omega t \cdot d\alpha(\omega) - \sin \omega t \cdot d\beta(\omega)]$$

where the given time series or stochastic process y_t is represented in terms of sinusoids with infinitesimal or noninfinitesimal coefficients $d\alpha(\omega)$, $d\beta(\omega)$. These are increments of real processes $\alpha(\omega)$, $\beta(\omega)$ which conversely can be retrieved from y_t as limits in the mean,

$$(A_2) \qquad \alpha(\omega) = \lim_{T\to\infty} \sum_{t=-T}^{T} (\sin \omega t/t)[y_t - E(y_t)];$$

$$\beta(\omega) = \lim_{T\to\infty} \sum_{t=-T}^{T} [(\cos \omega t - 1)/t][y_t - E(y_t)].$$

While $\alpha(\omega)$, $\beta(\omega)$ in general, are highly irregular, and not even of bounded variation, their statistical properties are quite simple. Their increments thus have zero expectations, and variances given by

$$(A_3) \qquad E[d\alpha(\omega)]^2 = E[d\beta(\omega)]^2 = \tfrac{1}{2}dF(\omega); \qquad 0 \leqq \lambda \leqq \pi,$$

where $F(\omega)$ is the cumulative spectrum of y_t.

Under (b) we quote the *predictive decomposition* given by the reviewer (1938) and developed by the use of spectral methods by A. Kolmogorov (1939), (1941) and N. Wiener (1949), and classified earlier work,

$$(1) \qquad y_t = \psi_t + \varphi_t \quad \text{with} \quad \varphi_t = \epsilon_t + \gamma_1\epsilon_{t-1} + \gamma_2\epsilon_{t-2} + \cdots$$

where the component ψ_t is deterministic in the sense that ψ_{t+k} for any $k \geqq 0$ can be exactly forecast on the basis of past observations $y_{t-1}, y_{t-2}, \cdots$ (exactly, inasmuch as the prediction error has zero expectation and zero variance) whereas the nondeterministic component φ_t takes the form of a moving linear summation of a sequence of mutually uncorrelated innovations $\epsilon_t, \epsilon_{t-1}, \cdots$.

By mistake the authors state (p. 30) that (A) covers (B), and that the deterministic component is nothing else than what is generated by the step-function component of the spectrum $F(\omega)$. As shown by Kolmogorov, however, the process may have an absolutely continuous spectrum and yet be completely deterministic. This fact gives ample evidence that the methods of spectral analysis are of fundamental relevance for parametric as well as for nonparametric approaches. It may be added that it is still an open problem how to extend Kolmogorov's last-mentioned result to multivariate processes. Incidentally, in this connection the authors only refer to Kolmogorov's preliminary note of three pages in *Comptes Rendus* (1939); in an earlier chapter they refer to his main work (1941) on representation (B), but they fail to mention that this last work which is in Russian is available in Spanish in *Trabajos de Estadistica* **4** (1953).

4. The book provides an array of spectral techniques of very general scope, the only assumption being that the time series under analysis are stationary or can be made approximately stationary by *ad hoc* devices. The principal methods are (1) J. Tukey's approach for estimating the spectral density in terms of the autocovariances of the given series y_t, and (2) Tukey's extension of this approach to multivariate processes by way of the cross-spectrum. Hence Cramér's representation (A) and its extension to multivariate processes is the key to the entire volume.

Granger-Hatanaka make it very clear that they limit their attention to nonparametric and essentially retrospective approaches; see p. 38: "The important problem of prediction has been well covered by other writers . . . and so need only be briefly mentioned here." The authors are of course in their undisputed right to limit the scope of their approach; they should however have spelled out the limitation in the title of the book. The crucial question is whether the spectral techniques, which are indispensable in many technological applications, can be applied with advantage to economic problems. Here of course the actual results of applied work are the only valid criterion. Quite generally it can be said that the focussing on the spectral function $F(\omega)$ and its derivative involves a loss of information, for as is clear from $(A_1 - A_3)$ the knowledge of $\alpha(\omega)$, $\beta(\omega)$ is equivalent to knowledge about y_t, whereas the knowledge of $F(\omega)$ only allows us to infer about the mean square properties of $\alpha(\omega)$, $\beta(\omega)$. Hence the question is whether this loss of information is compensated by some specific advantage in the applied work.

The reviewer is struck by an inner inconsistency between ends and means in the reported applications, Chapters 12–13. The lead-lag problems (Chapter 12) are clearly predictive and quantitative, and yet the spectral techniques in play are essentially nonparametric and retrospective. The data are from the National Bureau of Economic Research (NBER), and the analysis amounts to a comparative study of the NBER indicators, and directions and magnitudes of lead-lags emerging from the spectral techniques. The reviewer gathers that the results of the two lines of approach are not too different, or not more than can be expected from the conceptual differences at issue. The authors are aware that their techniques have shortcomings from the point of view of prediction, to judge from such statements as "it must be admitted that this study is greatly handicapped by the fact that what is meant by cycles in economics are not represented by a single frequency point but by a frequency band" (p. 216), and, referring to the fact that while the data used are extended up to June 1961 the charts that report the results all end in 1957: "This is certainly a serious drawback of the method used here. The reason for this is that we have lost data twice, . . . [namely, in connection with] . . . the trend-seasonal filter . . . and the complex demodulation" (p. 262).—The inventory cycle (Chapter 13) cries for a parametric multirelation model that specifies feedbacks and other causal relationships. Granting ". . . the inadequacy of cross-spectral analysis (in its present stage) to treat such feed-back relationships" (p. 268) the analysis focusses on a number of small sectors of the economy to avoid feedback effects on gross national income, and explores three hypotheses: the accelerator principle; a modified version of the same; and a "supply conditions" hypothesis. Summing up, the authors report (p. 293) that they have "failed to derive any clear-cut conclusions as to the choice among the hypotheses explored."

5. The book is announced as the first result of a Time Series Project at the Econometric Research Program of Princeton University, directed by Professor O. Morgenstern and advised from its earliest days by Professor J. Tukey. As

part of an ambitious program in a new direction the volume calls for special attention, and an appraisal of the program. In this last respect the reviewer is ambivalent. Most of the current approaches in econometric model building are parametric; progress and success are not uniform, and there is certainly room for other types of approach; it is always a good thing to give methods from other areas a chance to cope with the tough problems of economics; the enthusiasm of the authors in exploring the possibilities of spectral analysis is most appealing; appealing is also their frank admission of inconclusive or negative results in the applied work. At the same time the reviewer is taken aback by some very poor argument at the fundamental level of ends and means, on what in French or German would be called the "problématique" or "Problematik" of the Time Series Project.

In fairness to the authors, the responsibility for the views expressed in the volume on fundamental matters must to a large extent rest with the initial planning of the Time Series Project. In the Foreword, Professor Morgenstern gives a very lop-sided sketch of the historical background, forgetting completely about Yule's autoregressive model (1927) and its rapid propagation into econometrics in the 1930's. Further he evokes the memory of John von Neumann in support of the general approach of the Project. The reviewer doubts that von Neumann would have approved of the rejection (p. 3–4) of parametric model building as obsolete: "At one time the fitting of models to the available data was considered as an essential part of the analysis but the more recent methods do not place any great emphasis on model-building." This view rhymes very badly with the explanation offered on the inconclusive results in Chapter 13: "The reason for this failure, however, is not in the partial cross-spectral analysis but in the lack of adequate data . . ." (p. 293). Then follows a drastic shift in the argument: "The availability of statistical techniques is but one of many conditions that determine what kind of empirical studies can be done." How true! And "Without great advancements in other conditions [read: more and better data] the improvement of statistical techniques alone cannot produce a great result." Yes, indeed, but what if spectral analysis requires data that extend over ten or hundred times more cycles than at present? In the meanwhile, parametric models are needed to squeeze the data for as much information as possible. This is so much the more so as the parametric approaches have thus far made only modest headway in econometric prediction problems, including the areas dealt with in Chapters 12 and 13. If experience has taught us anything in econometrics it is that unirelation and other low-information approaches do not suffice as a basis for economy-wide prediction problems. The breakdown in 1929 of the Harvard Business Barometer was manifestly an important factor in giving incentive to the initiation of multirelation model building in the 1930's in the hands of Jan Tinbergen.

What the reviewer misses most in the present volume as starting a new program is a discourse from scratch on what types of economic problems are potentially good candidates for the application of spectral techniques. And the reviewer is far from seeing the reported negative or semi-negative applied results as evidence that such candidates do not exist, even in the present stage of evolution of economic data. One consideration is that spectral techniques are useful in situations when observations of the phenomena that interest us are not available directly, only indirectly by way of signals with a wave pattern. To illustrate the argument, not to venture a suggestion that this is a good candidate, we may think of the periodic pattern of expenditures of weekly wage earners; maybe under different phases of the boom-recession cycle these weekly patterns have a different structure, information about which may be picked up by some combination of sampling surveys and spectral techniques?