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SPECTRAL ANALYSIS OF THE RELATION BETWEEN EMPLOYMENT CHANGES AND OUTPUT CHANGES, 1958-1966

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SPECTRAL ANALYSIS OF THE RELATION

BETWEEN EMPLOYMENT CHANGES AND OUTPUT CHANGES, 1958-1966*

by

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I. Introduction

This paper discusses some results of a spectral analysis of the relationship between gross changes in employment and changes in output in a large number of small industry groupings. Comparisons among the industries in these relationships is made in order to determine if the spectra are different and if the differences which are found can be explained by differences in the characteristics of the labor employed in the industries.

Spectral analysis has been applied to a problem in labor economics in only one case [4]; the cause of this dearth of studies using spectral techniques has undoubtedly been the limited number of observations we have on most variables relating to labor. More important, even if we had such information, there are relatively few problems for which spectral analysis might be expected to give interesting results. While one could, as Hatanaka [4] has done, examine the cross-spectra of two seemingly randomly chosen series to exhibit their relationship at certain low, presumably cyclical frequencies, such analysis adds little to our understanding of how workers and firms behave.1/ Indeed, spectral analysis does not seem to have produced much new evidence about cyclical relationships, perhaps because we have so few observations on complete cycles in economic

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activity, or perhaps because these low-frequency movements are of such irregular length as to be undetectable by spectral analysis.[2/] Thus the major use of spectral analysis in labor economics must be in the analysis of behavior reflected at higher frequencies, particularly those we call "seasonal," for it is only at these frequencies that we have enough complete "cycles" of behavior to make statistically significant inferences.

II. Theory

Interindustry differences in the relation between employment and output represent one area in which a theory can be developed and then tested by examining behavior at the seasonal frequencies in a spectral analysis. Moreover, the theory cannot be examined empirically, at least as it applies to seasonal changes, by use of the familiar regression techniques of econometrics.

Let Y be output, E employment, K capital, I investment, N total new hires, Q total quits, L layoffs and M miscellaneous gross changes in employment. Assume that we can identify a group of manufacturing establishments with the same production processes and the same quality of labor used in these processes. Further assume that there exists a production function (1) for this group of plants.

$$Y(t) = E(t)^{\alpha} K(t)^{1-\alpha} \tag{1}$$

Differentiating this function logarithmically with respect to time we obtain

$$\frac{\dot{Y}(t)}{Y(t)} = \alpha \frac{\dot{E}(t)}{E(t)} + (1-\alpha) \frac{\dot{K}(t)}{K(t)} \quad . \tag{2}$$

Substituting into (2) for employment change,

$$(3) \qquad \frac{\dot{Y}(t)}{Y(t)} = \alpha \frac{[N(t) - Q(t) - L(t) + M(t)]}{E(t)} + (1-\alpha) \frac{I(t)}{K(t)}$$

where $I(t)$ is net investment.

Since observations on $I(t)$ are not available at the disaggregated level to which we apply this model, we assume that $\frac{I(t)}{K(t)}$ is a constant over time and rewrite (3) in terms of percentage changes:

$$(4) \qquad \dot{y} = a(n - q - \ell + m) + b \quad .$$

Since this equation was derived by manipulating the technological relation (1), it does not by itself give any behavioral implications. It can, however, be clothed with implications for behavior in different industries if we make some further assumptions.

Assume that some amount of specific training is required for jobs in an industry and assume further that firms in the industry have no control over the level of quits from the industry.[3/] This implies that firms' demand for new hires and layoffs are residual demands from the level of quits.

Given these assumptions firms would, in order to avoid making unnecessary investments in the training of new workers and to avoid losing the investments in workers they already employ, prefer to modify the size of their work forces by changing the level of new hires rather than that of layoffs. In particular, they should prefer to meet seasonal changes in output change by increasing or decreasing new hires and trying to avoid layoffs as much as possible. The present analysis abstracts from the existence of workers who are hired for a short period in full knowledge that they will be laid off at the end of that period (women in the canning industry are a standard example of such a phenomenon). Such hiring and laying off will of course give rise to seasonality in the layoff series as well as in new hires. Nonetheless, the other factor, that involving the replacement of workers who quit, will give rise to a seasonal component in new hires which is greater than that in layoffs, if output change itself has a seasonal component.

If supply conditions are assumed to remain constant, firms in the industry in which training is essential for most workers will have an incentive to minimize changes in new hires and layoffs in response to seasonal variations in output changes. Such firms will try to avoid incurring training costs in workers who are only needed to help meet seasonal peaks in product demand. Industries in which little training is required to enable potential new hires to work efficiently might be expected to expand and contract their work force to a greater extent as product demand changes seasonally.

For industries in which training costs are high, we should expect relatively flat spectra for the series on new hires and layoffs, even when the series on output change shows decisive peaks at the seasonal frequencies. Industries in which specific training is relatively unimportant might be expected to have hires, layoffs and output changes series with spectra exhibiting marked peaks. A comparison of these spectra for a number of industries thus provides evidence as to whether the specific training hypothesis is a valid explanation for interindustry differences in the behavior of gross changes in employment.

It may be that a theory of union wage policy and of employer reaction to that policy can be constructed that would explain differences in the spectra of the employment change series both within and among industries.[4/] It is certainly true that the analysis of this paper does not discriminate between possible causes of the phenomena under consideration, but instead merely advances the specific training hypothesis as a reasonable one.

Since the series on new hires, quits, etc., represent changes in the level of employment, we should not expect, ceteris paribus, to find much power at the lowest frequencies in the spectrum. If, however, the industry rate of growth or decline changes slowly during the period of observation, one would expect substantial power at the low frequencies. Such power would also exist in the spectra for a steadily growing industry if biased technological change were occurring in the industry. Labor-saving technical change would, for example, cause a secular decrease in the elasticity of each series on gross employment change with respect to output change, and this trend might also produce an accumulation of power at low frequencies.

III. Data

Data for twenty-eight industries form the basis for the analysis presented here. The industries considered comprise all three- and four-digit industries for which monthly production data are available and for which these data are based on physical or value measures rather than on manhours worked. (Use of production data based on manhours would have, of course, little value in a study relating employment change to output change.)

The production data are computed by the Federal Reserve Board on the basis of trade association data and reports collected by the Bureau of the Census [3]. The series on new hires, quits and layoffs are published by the Bureau of Labor Statistics on the basis of a sample covering the majority of workers employed in manufacturing. Miscellaneous gross changes in employment were derived by the following identity:

$$m \equiv (a - n) - (s - q - \ell) \tag{5}$$

where a is total accessions and s total separations. Because of the diverse changes contained in this series it is difficult to form any hypothesis about the shape of its spectrum in different industries and I ignore it in further discussion.[5/] Data on all these series are available and were used in the analysis, from January 1958 through December 1966.

The twenty-eight industries were divided into two groups according to the level of specific training required in each of them, as estimated by Eckaus [2] on the basis of the occupational mix in each industry and the Employment Service's estimates of specific vocational training required for each occupation. Table 1 shows this breakdown and also gives measures of the extent of unionism, of the occupational structure in each industry, and of wages and salaries per worker in each industry. As can be seen from Table 1, industries in Group I are generally those which are more heavily unionized and in which the wage level is relatively high. This points up the difficulty of discriminating between the specific training hypothesis and some theory of employer behavior in the presence of unionism on the basis of whatever results this study brings out.

Table I

Industry & Group	SIC	(1) Specific Training Required 1950 (in years)	(2) Workers in Unionized Establish-ments, 1958 (percent)	(3) Semi-skilled and Unskilled Workers, 1960 (percent)	(4) Payroll per Employee, 1963 (dollars)
Group I: Cement, hydraulic	324	1.05	77.9	56.8	6522
Iron and steel foundries	332	1.15	88.6	50.6	6179
Aluminum rolling, drawing and extruding	3352	1.24	88.6	49.5	6941
Nonferrous foundries	336	1.24	88.6	49.5	5950
Metal cans	341	1.26	70.6	43.4	7081
Heating equipment	3433	1.26	70.6	43.4	5803
Household refriger-ators and freezers	3632	1.38	72.8	46.0	6501
Household laundry equipment	3633	1.38	72.8	46.0	6291
Radio and TV receiving sets	365	1.38	72.8	46.0	5053
Plastic materials and resins	2821	1.47	65.4	37.9	7130
Synthetic fibers	2823,4	1.17	65.4	53.1	6193
Group II; Sawmills and planing mills	242	.78	43.8	70.7	3856
Millwork	2431	.78	43.8	70.7	4914
Veneer and plywood	2432	.78	43.8	70.7	4909
Glass containers	3221	.88	77.9	61.9	5467

(continued)

Table I (continued)

Industry & Group	SIC	Specific Training Required 1950 (in years)	Workers in Unionized Establish-ments, 1958 (percent)	Semi-skilled and Unskilled Workers, 1960 (percent)	Payroll per Employee, 1963 (dollars)
Brick and structural clay tile	3251	.79	77.9	67.9	4555
Confectionary and related products	207	.70	68.1	61.9	4490
Cigarettes	211	.63	62.6	67.5	5146
Cigars	212	.63	62.6	67.5	3285
Wool weaving and finishing	223	.98	30.1	72.9	4278
Men's and boys' suits and coats	231	.64	59.7	80.0	4029
Men's and boys' furnishings	232	.64	59.7	80.0	2943
Paperboard	263	.82	75.5	57.7	6767
Corrugated and solid fiber boxes	2653	.97	75.5	59.2	5834
Tires and inner tubes	301	.97	80.6	58.5	7292
Other rubber products	302,3,6	.97	80.6	58.5	5537
Leather tanning and finishing	311	.79	49.3	71.8	5198
Footwear, except rubber	314	.55	49.3	77.4	3541

Column 1: Specific Vocational Preparation, in years, as estimated in [2, pp. 187-89]. These figures and those in Column 3 are based on the Census breakdown of industries, a division which is not as fine as the three-digit SIC breakdown. Thus some of the industries in our sample fall into the same Census category and will have identical figures in Columns 1 and 3, while in most cases the figures in these columns are based on other, closely allied industries, as well as on the industry for which we have listed them. While this is undoubtedly a problem, the estimates in this table are the finest breakdown available. Moreover, in view of the similarity of industries grouped together by the Census, the errors should not, I believe, be overwhelming.

Table I (continued)

Column 2: Percent of workers in the industry employed in establishments in which the majority of workers are unionized. H. M. Douty, "Collective Bargaining Coverage in Factory Employment," Monthly Labor Review, April, 1960, page 347.

Column 3: Operatives + service workers + laborers as a percent of total employment in the industry grouping, Census of Population, 1960, PC(2)-7C, Subject Report, Occupation by Industry, Table II.

Column 4: Total payroll divided by number of employees on the payroll in March, 1963, in operating establishments, Census of Manufactures, 1963, Volume I, Summary Statistics, "General Summary," Table III, pp. 48-62.

IV. Estimates of Spectra and Cross-Spectra

The spectra for the series on new hires, quits, layoffs and output changes were estimated using prewhitened data, where the prewhitening was done by a stepwise autoregressive procedure [8] that selected from the detrended series $x(t) = X(t) - \bar{X}$ those lags which gave significant coefficients. The spectra were then computed using the so-called Parzen weighting scheme for the autocovariances, with weights defined as:

$$W\left(\frac{\ell}{M}\right) = \begin{cases} 1 - \dfrac{6\ell^2}{M^2}\left(1 - \dfrac{\ell}{M}\right) & 0 \leq \ell < \dfrac{M}{2} \\ 2\left(1 - \dfrac{\ell}{M}\right)^2 & \dfrac{M}{2} \leq \ell \leq M \end{cases} \qquad (6)$$

where M is the truncation point in the summation of the series in

$$f_{xx}(k) = \frac{1}{2\pi}\left\{c_{xx}(0) + 2\sum_{\ell=1}^{M} c_{xx}(\ell)\cos\frac{\pi k\ell}{M}W\left(\frac{\ell}{M}\right)\right\},$$

the formula for the spectrum of the process $x(t)$. In this study we restricted the series to a truncation point of 36 months, since our observations on the series were limited to 108 months. Finally, the raw spectra were "recolored" by dividing at each frequency by the transfer function of the fitted autoregression at that frequency.

It is impossible to present graphically all 112 spectra which were computed in this analysis, so we present four spectra for a typical industry in each of our two groupings and a discussion of results contained in the appendices. Appendix A presents a coded summary of the shapes of the spectra for each of the 112 series. While this coding is unfortunately based on what may be arbitrary visual distinctions, it is the only practical way of summarizing all the results of the analysis. Remembering that our theoretical argument hinges on the presence of seasonality in the output changes series, we must first inquire whether this condition is satisfied. In all but four industries we find strong peaks in the spectra of output change at the seasonal harmonics and only one of the four without strong seasonality fails to show at least moderate seasonality in the output changes series. The assumption that there is significant seasonal movement in output thus seems well satisfied. The presence of greater power at the higher frequencies in these spectra for most industries is undoubtedly due to the use of percentage output change, a procedure which produces low-order negative autocorrelation if little positive autocorrelation existed in the original series.

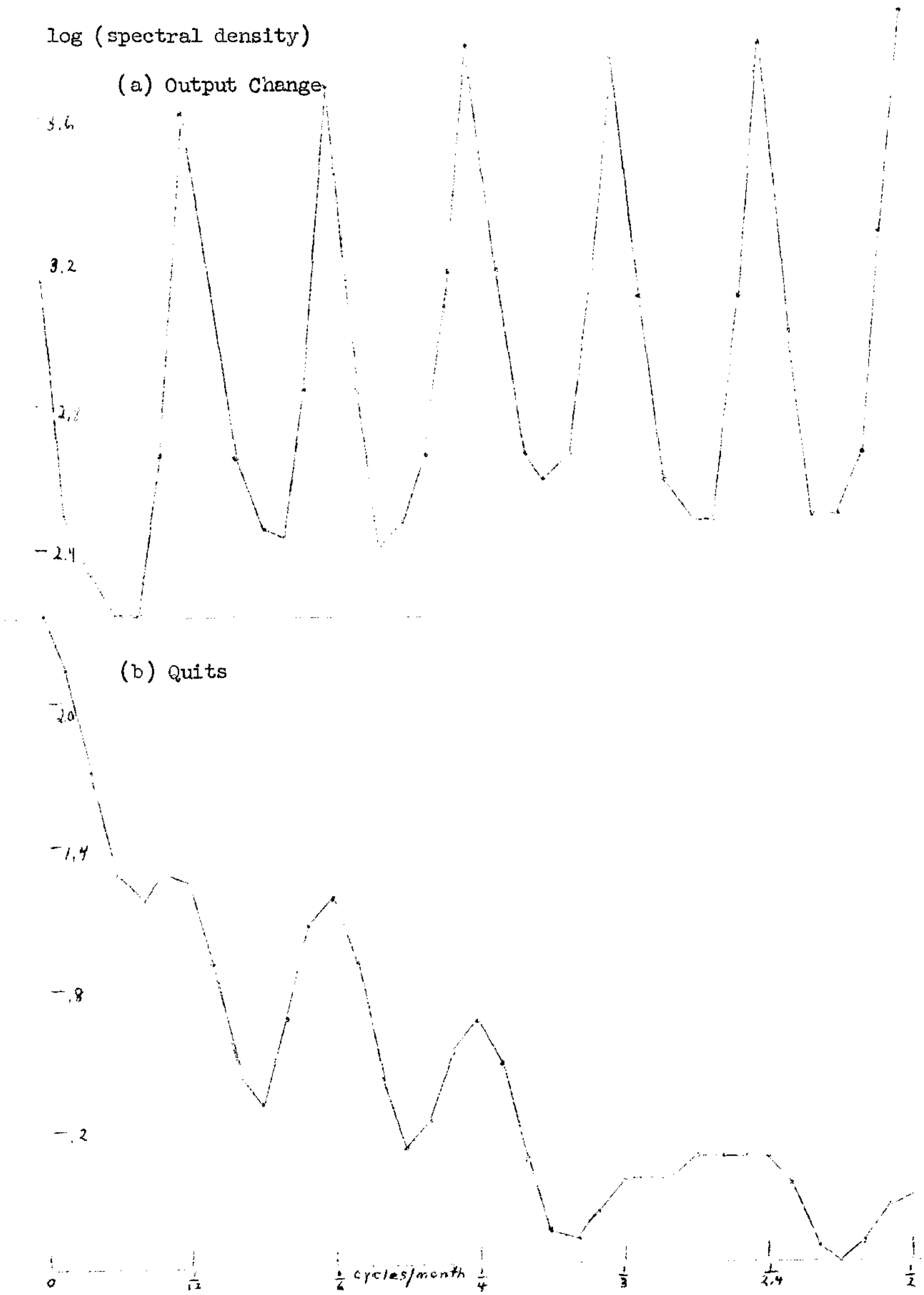
We also assumed that quit rates in the various industries have similar spectra, indicating, if layoffs and new hires have substantially different spectra, that the level of quits is independent of conditions in the particular small industry grouping. This assumption also appears to be borne out by the results of this analysis. The spectra for the new hires and layoffs series vary greatly in shape in the different industries, but those for quits have, with the exception of the household refrigeration industry (SIC 3632), moderate or strong seasonal peaks.

In short, both of our assumptions appear valid (or at least as valid as one may ever claim on the basis of empirical work) and we can proceed to examine whether one prediction based on the presence of specific training, namely the greater seasonality of new hires than of layoffs, is demonstrated empirically. A comparison of the spectra of these two series in each of the twenty-eight industries shows eighteen for which the new hires series have sharper peaks at the seasonal harmonics than do the layoffs series. In six industries the strength of seasonal movements appears the same as between the two series, while in four others the layoffs series has a stronger seasonal component than the new hires series. Thus in a substantial majority of industries the results can be explained by the effects of the specific training of workers on employer behavior.

Figures Ia, Ib, IIa, and IIb illustrate these results for the non-ferrous foundries industry, SIC 336, representing Group I, and for the paperboard industry, SIC 263, representing Group II. In the both industries the spectra for both output change and quits have marked peaks at the seasonal harmonics, with the spectral density at the harmonics being more than ten times as great as the density at the nearby troughs in most cases. The greater seasonality in new hires is especially apparent in the paperboard industry, in which the spectrum of the new hires series has seasonal peaks as strong as those in the output change series, while the spectrum of layoffs has only small blips at the seasonal harmonics.

The specific training hypothesis also predicts that industries in what we have designated Group I should have spectra for new hires and layoffs which are much flatter than those in the less-skilled industries in Group II. In comparing the spectra of the new hires series between these two groups we find that fifteen of the seventeen industries in Group II have new hires series with strong or moderate seasonal peaks, while this is true for only five of the

Figure I: SIC 336



log (spectral density) Figure I: SIC 336

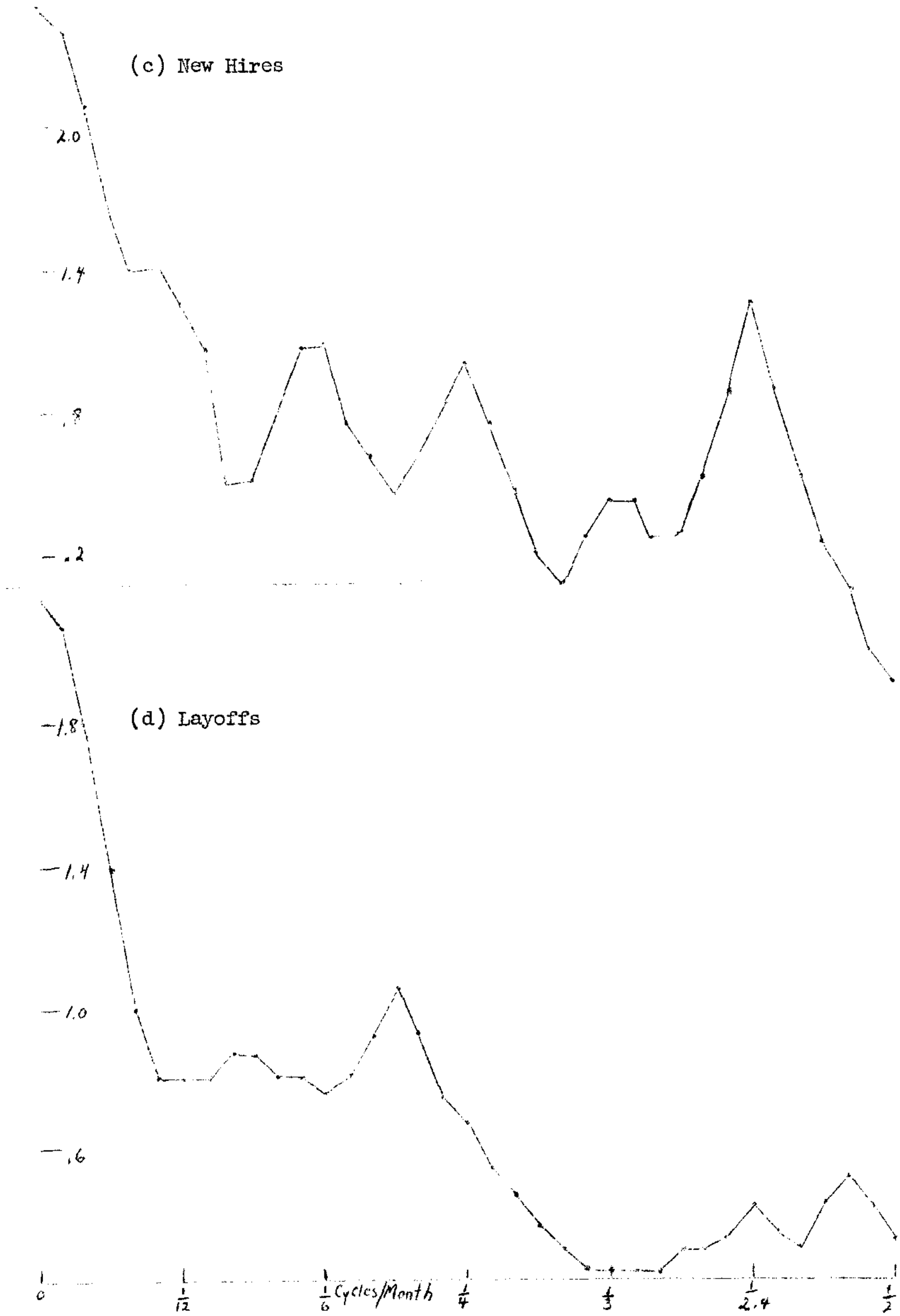
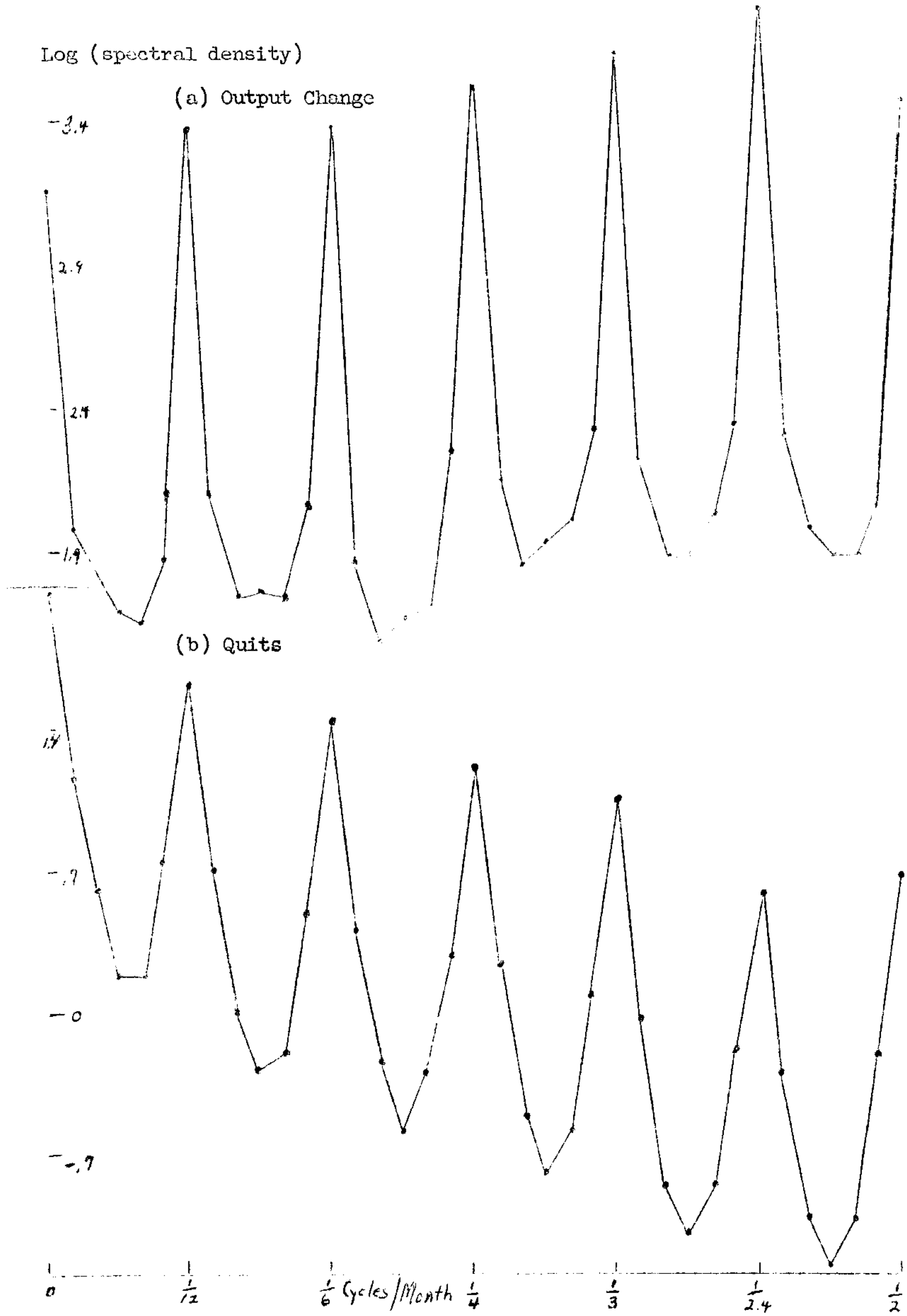
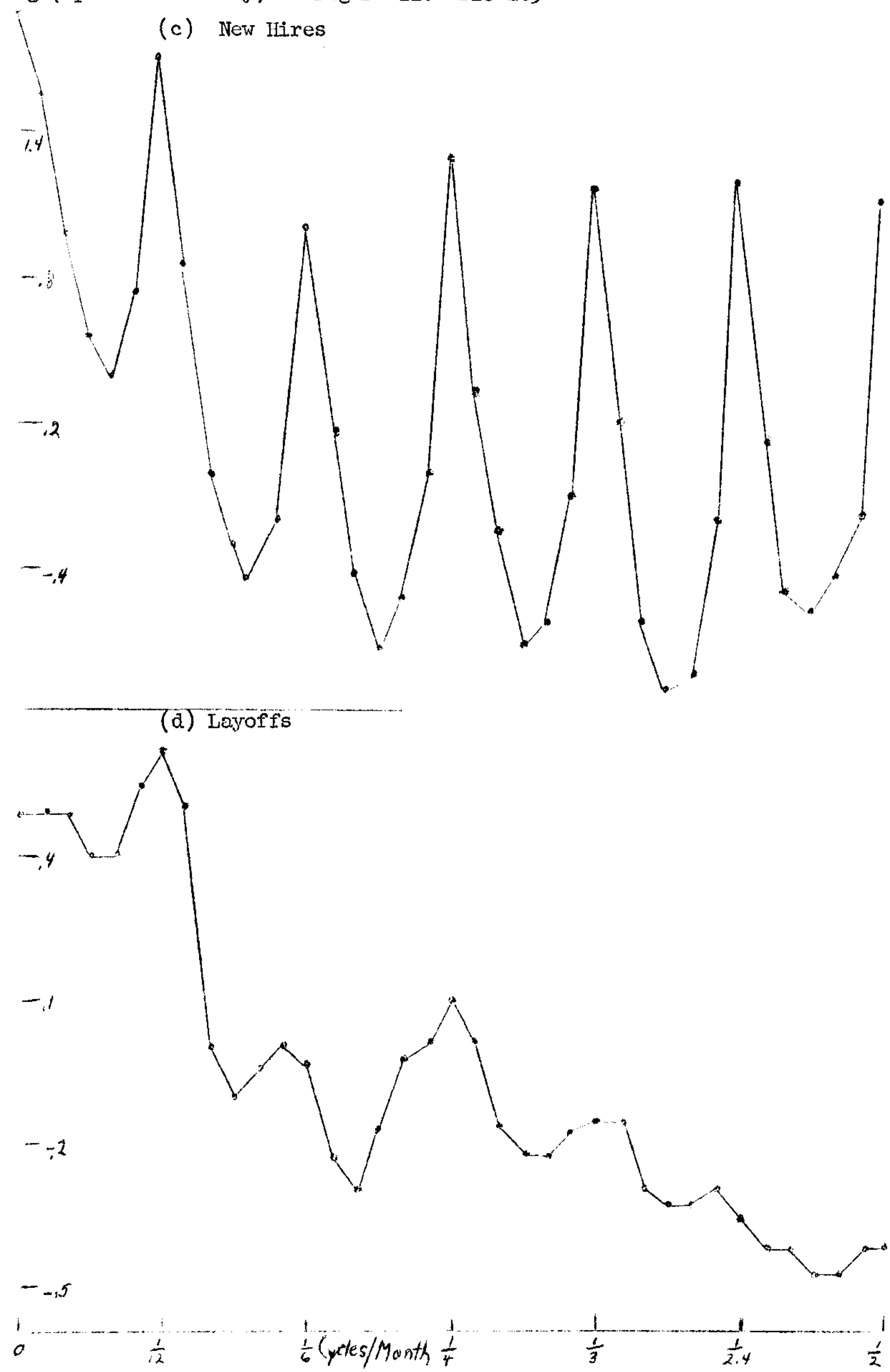


Figure II: SIC 263



log (spectral density)   Figure II: SIC 263



eleven industries in Group I. It thus appears that in those industries in which new workers must be trained for their jobs the level of new hires fluctuates much less seasonally than it does in those industries which require less specific training.

In the case of layoffs there is some evidence, albeit rather weak, that seasonal fluctuations are more marked in those industries which require relatively little investment in specific training. In five of the eleven industries in Group I the spectra of the layoffs series show no seasonality, while this is true for two of the seventeen industries in Group II. (Only three of the eleven industries in Group I have strong or moderately seasonal layoffs, while eight of seventeen in Group II have such seasonality.) Assuming that this evidence is not satisfactory support of the specific training hypothesis, I proceeded to examine the spectra on quits in the Group II industries, in order to ascertain whether those industries in which the spectra of layoffs were especially flat were also those in which quits were strongly seasonal. If such were the case it would indicate that seasonal fluctuations in quits enabled firms in these industries to avoid layoffs. Unfortunately, there is no such evidence, and we must remain satisfied, at least for the purposes of this paper, with the weak evidence that layoffs, like new hires, show the expected differences between the two types of industry.

These last two points are illustrated by comparing Figures Ic, Id, IIc and IId. In the nonferrous foundries industry the spectrum of the new hires series has only small peaks relative to those of the same series for the paper-board industry. In addition, layoffs in the nonferrous foundries industry have no significant seasonal fluctuations, while layoffs from the paperboard industry have significant, but weak seasonal fluctuations.

Finally, it should be noted that the spectra for new hires, quits and layoffs in nearly all of the industries have less power at higher frequencies than at the very low frequencies. As was mentioned above, this phenomenon could be due to any of several causes, either singly or together, ranging from technological change to growing output. It is impossible by means of spectral techniques alone to explain this result.

V. Conclusions

The theoretical effects of required specific training of workers on hiring and firing appear, for the most part, to be substantiated by this interindustry comparison of seasonal behavior. We find that in most industries seasonal fluctuations in new hires are greater than those in layoffs, as expected if entrepreneurs minimize costs by avoiding layoffs of those workers in whom they have an investment in the form of specific training. Furthermore, it is clear that in industries in which specific training of workers is more important, the level of new hires fluctuates much less seasonally than it does in those industries in which less specific training is required. This difference between the two types of industry is also reflected, though not quite so clearly, in the seasonal behavior of layoffs.

The results of this analysis have an interesting implication for wage theory and perhaps for policy. Popular literature contains many discussions of the effect of the rise of vested pension plans on worker mobility, insofar as they increase the incentives for workers to avoid frequent moves. Oi [6, p. 545] has analyzed empirically the effects of specific training on workers' desires to remain in their present jobs. Both of these points are based on the supply behavior of workers. The results of this present analysis, in particular the weak seasonality of layoffs in most industries, especially those which require more training of workers, indicate that investment in training works on the <u>demand</u> as well as on the supply side to decrease the interfirm mobility of labor.

APPENDIX A

Summary of the Shapes of the Spectra for the Time Series

Table A-1

Group I Industries

SIC	Output Change		Quits	
324	SS-F	sharp seasonal peaks	SS-D	sharp seasonal peaks
332	SS-F	sharp seasonal peaks	MS-D	very high power at lowest frequency
3352	WS-U	36-month cycle also	SS-D	sharp seasonal peaks
336	SS-U	sharp seasonal peaks	MS-D	high power at lowest frequency
341	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
3433	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
3632	SS-U	sharp seasonal peaks	WS-D	sharp peak at 6-month cycle
3633	SS-U	sharp seasonal peaks	SS-D	high power at low frequencies
365	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
2821	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
2823,4	MS-F	sharp peaks at 12, 4-month cycles, irregular elsewhere	SS-D	sharp seasonal peaks

SIC	New Hires		Layoffs	
324	SS-D	sharp seasonal peaks	MS-D	no peaks at high-frequency seasonal harmonics
332	WS-D	sharp peak at 4-month cycle only	NS-D	irregular fluctuations
3352	WS-D	weak peaks at all seasonals	NS-D	irregular fluctuations
336	WS-D	missing 12-month, 2-month peaks entirely	NS-D	irregular fluctuations
341	MS-D	sharp peaks at 12, 6-month cycles	SS-F	sharp seasonal peaks
3433	WS-D	weak peaks at all but 2-month cycle	WS-D	36-month cycle also
3632	NS-D	nearly flat except for high power at low frequencies	MS-F	sharp peak at 12-month cycle, others weak
3633	WS-D	weak peaks at the lower-frequency seasonal harmonics	NS-F	irregular fluctuations

Table A-1 (continued)

365	MS-D	fairly sharp peaks, except at 3, 2-month cycles	WS-D	irregular except for moderate peaks at 12, 6-month cycles
2821	SS-F	sharp seasonal peaks	NS-D	nearly flat, except for some power at lowest frequencies
2823,4	SS-D	sharp seasonal peaks	WS-D	weak peaks at all but 4, 3-month cycles

KEY: SS - pronounced peaks at all or all but one of the seasonal harmonics
MS - peaks at most or all seasonal harmonics, but some weak
WS - peaks at some seasonal harmonics, or small rises at most of the seasonal harmonics
NS - no evidence of significant power at the seasonal frequencies
U - more power at the higher frequencies than the lower ones
F - spectrum is relatively flat
D - more power at the lower frequencies than the higher ones

Table A-2

Group II Industries

SIC		Output Change		Quits
242	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
2431	SS-F	sharp seasonal peaks	SS-D	sharp seasonal peaks
2432	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks, high power lowest frequencies
3221	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
3251	SS-F	sharp seasonal peaks	SS-D	sharp seasonal peaks, except at 2-month cycle
207	SS-U	sharp seasonal peaks	SS-D	sharp peaks, misses 2-month cycle
211	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
212	SS-U	sharp seasonal peaks	MS-D	weak at 12, 3-month cycles
223	MS-F	sharp peaks at 12, 6, and 2-month cycles	SS-D	sharp seasonal peaks
231	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
232	SS-U	sharp peaks, weak only at 12-month cycle	SS-F	sharp peaks, weak only at 12-month cycle
263	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
2653	SS-U	sharp seasonal peaks	SS-D	sharp seasonal peaks
301	MS-U	all peaks, but weak at 12, 4-month cycles	SS-D	sharp seasonal peaks
302,3,6	SS-U	sharp seasonal peaks	MS-D	all peaks, sharp only at 6, 4, and 2-month cycles
311	SS-U	sharp seasonal peaks	SS-D	sharp peaks, misses 2-month cycle
314	SS-U	sharp seasonal peaks	MS-D	missing 4-month cycle, weak at 2-month cycle

		New Hires		Layoffs
242	MS-D	peaks at 6, 3, and 2-month cycles are weak	MS-D	weak at 3-month cycle, missing 2-month cycle
2431	MS-D	peaks at 6, 3, and 2-month cycles are weak	WS-D	sharp peak at 12, 2-month cycles, missing others entirely
2432	SS-D	sharp seasonal peaks	NS-D	nearly flat, except for D
3221	MS-D	weak at 3-month cycle, missing 2-month cycle	MS-D	weak at high-frequency seasonal harmonics
3251	MS-D	weak at 4, 3-month cycles, missing 2-month cycle	SS-F	sharp seasonal peaks
207	SS-D	missing 3-month cycle	SS-F	sharp seasonal peaks

Table A-2 (continued)

211	MS-D	peaks at 6, 2-month cycles are weak	MS-F	weak at 6-month cycle, missing 2-month cycle
212	NS-D	irregular fluctuations	MS-U	sharp peaks at 6, 4-month cycles
223	SS-D	sharp seasonal peaks	WS-D	sharp peak only at 12-month cycle
231	WS-D	all peaks weak	WS-D	see Appendix B
232	SS-D	sharp seasonal peaks	WS-D	all peaks weak
263	SS-D	sharp seasonal peaks	WS-D	all peaks weak, missing 2-month cycle
2653	SS-D	sharp seasonal peaks	WS-D	weak peaks, missing high-frequency seasonal harmonics
301	MS-D	weak at 6, 3-month cycles	NS-D	irregular fluctuations
302,3,6	MS-D	sharp peaks at 4, 2.4-month cycles	WS-D	all peaks weak
311	SS-D	sharp seasonal peaks	MS-D	sharp peak at 12-month cycle misses 4-month cycle
314	SS-D	sharp seasonal peaks	MS-D	weak at 12, 4, and 2.4-month cycles

KEY: See key to Table A-1

APPENDIX B

Note on the Effects of an Autoregressive Prewhitening Procedure

The prewhitening procedure described in the text selected a 36-month lag with a coefficient -.439 for the layoffs series in men's and boys' suits and coats (SIC 231). The spectrum was then computed from the prewhitened data and recolored by dividing the raw spectrum by the transfer function

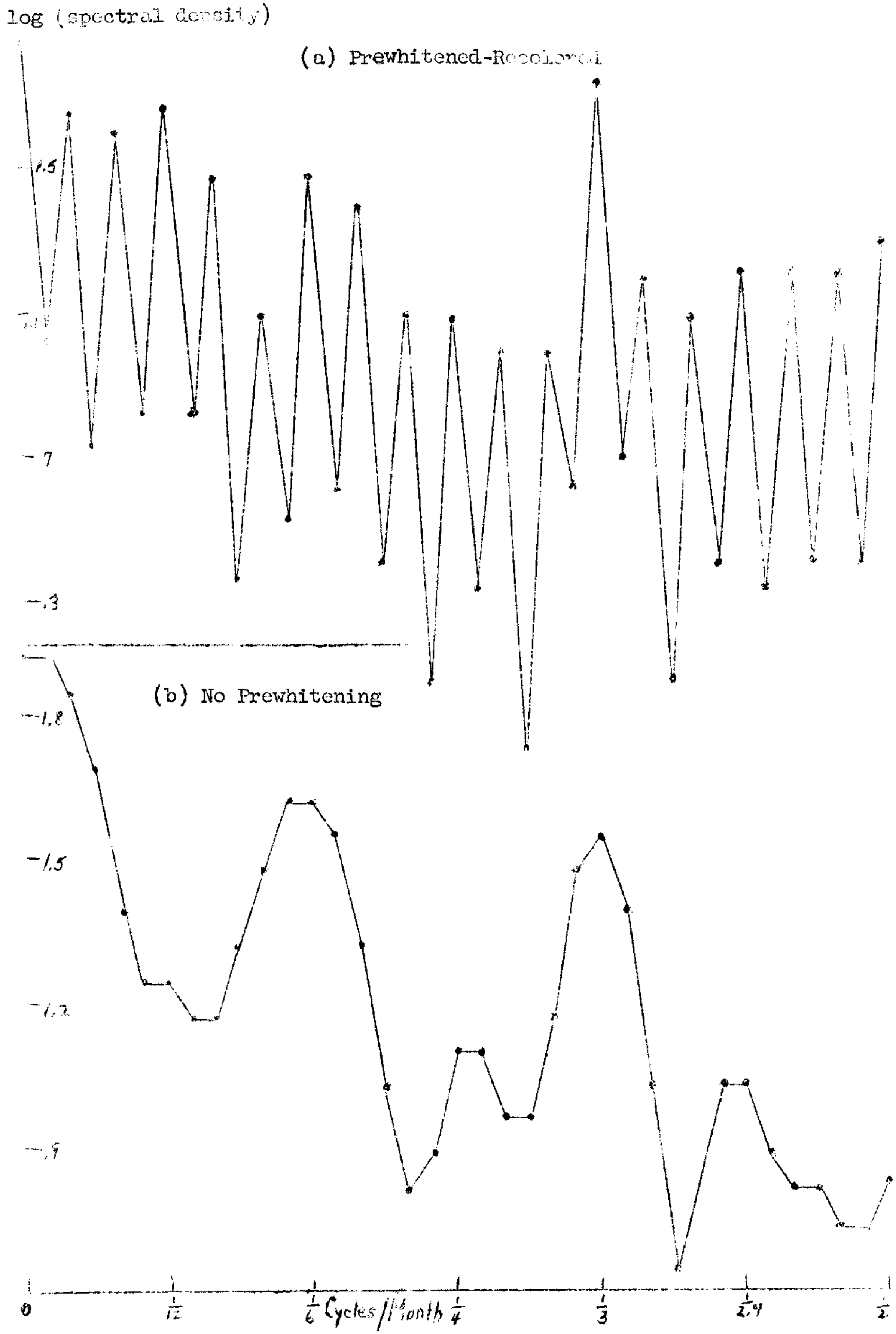
$$\text{(B.1)} \quad \left|L\left(\frac{\pi j}{36}\right)\right|^2 = \left[1 - .439e^{i36\left(\frac{\pi j}{36}\right)}\right]\left[1 - .439e^{-i36\left(\frac{\pi j}{36}\right)}\right], \quad j = 0, 1, \ldots, 36$$

which takes the value .3143 at the frequencies $\frac{j}{72}$, $j = 0, 2, \ldots, 36$ and 2.072 at the frequencies $\frac{j}{72}$, $j = 1, 3, \ldots, 35$. This filter resulted in the unusual spectrum shown in Figure B.I.a.

Examination of the raw data for this series shows why the stepwise regression procedure selected a lag of thirty-six months. As is evident from Figure B.II there is only weak seasonality in the data, and there are two outlying values thirty-six months apart (at the troughs in this industry of the 1958 and 1961 recessions).

The spectrum was recomputed without any prewhitening with the resulting spectrum shown in Figure B.I.b. The oscillatory pattern has disappeared and we are left with a weak seasonal pattern. It is interesting to note that this was the only series for which the prewhitening-recoloring procedure changed the spectrum significantly from its shape without this procedure. In the seven industries for which all four spectra were reestimated without prewhitening, the only change was a slight blurring in several of the series in the peaks at the seasonal harmonics. The relative insensitivity of the spectral shapes to the use or neglect of prewhitening is hardly surprising, in view of the absence of really sharp changes in the spectral density function. (In none of the spectra estimated was there a greater than hundred-fold difference between adjacent frequencies.) What is surprising is that the peculiar pattern in the raw data of this series coupled with the prewhitening procedure should have combined to produce such an unusual result.

Figure B.I: SIC 251, Layoffs



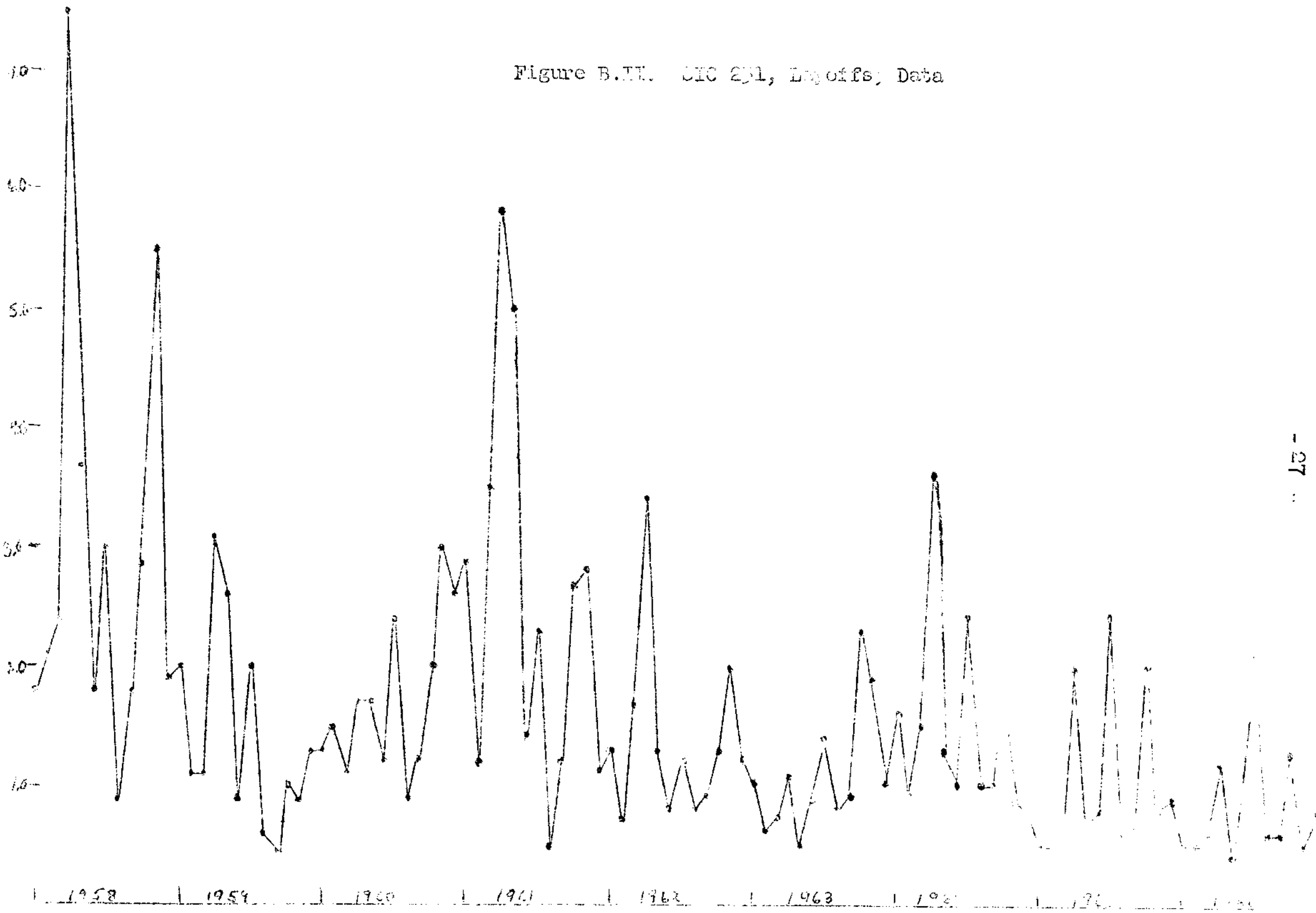


Figure B.II. SIC 251, Layoffs, Data

FOOTNOTES

1/ An example closely related to the subject of this paper is an analysis carried out by Hatanaka [4, pp. 238-242]. He computed the cross-spectrum of the aggregate layoff rate and the aggregate level of industrial production. As we show below, this comparison does not make economic sense, and its only rationale must be as an examination of two of the National Bureau of Economic Research business cycle indicators.

2/ Aside from the difficulty in getting resolution fine enough to allow us to isolate low-frequency cycles when we have limited amounts of data, the limited number of complete cycles available in such data is what really limits the usefulness of spectral techniques at low frequencies. In twenty years of data we may have only three or four complete cycles and may not be able to make inferences about the process generating the data. For an explicit discussion of this point see [9, p. 289] and [5, pg. 251].

3/ This latter assumption seems justified on the basis of other work I have done on this subject. In a simultaneous-equation model in which seasonal changes are held constant I found that the level of quits appears to depend only on the level of unemployment. The validity of this assumption as it regards seasonal changes can be substantiated by spectral analysis. If we find that the spectra of the series on quits in different industries are similar to each other, yet different in shape from the spectra of output changes or the other gross employment change series for the industry, we might infer that they are related to some factor or factors not specific to any particular industry.

4/ Ulman [7] examines the level of quits and that of wages for a cross-section of industries and cites union pressure in high-wage industries as causing wages in those industries to be greater than the marginal product of labor in those industries. This excess is a rent to workers in these industries and gives them an incentive to remain at their present jobs. Such an explanation sheds no light, however, on interindustry differences in the behavior of gross changes in employment over time.

5/ Miscellaneous gross changes include rehires, transfers from other plants owned by the same firm, and "terminations of employment because of discharge, permanent disability, death, retirement, transfers to another establishment of the company and entrance into the Armed Forces." [1, p. 783].

REFERENCES

[1] Bureau of Labor Statistics, Employment and Earnings Statistics for the United States, 1909-66, Bulletin 1312-4, (Washington: United States Government Printing Office, October 1966).

[2] Eckaus, R. S., "Economic Criteria for Education," Review of Economics and Statistics, 46: 181-190 (1964).

[3] Federal Reserve System, Board of Governors, Industrial Production, 1957-59 Base, (Washington: United States Government Printing Office, 1962).

[4] Granger, C. W. J., and M. Hatanaka, Spectral Analysis of Economic Time Series, (Princeton: Princeton University Press, 1963).

[5] Nerlove, Marc, "Spectral Analysis of Seasonal Adjustment Procedures," Econometrica, 32: 241-286 (1946).

[6] Oi, Walter Y., "Labor as a Quasi-Fixed Factor of Production," Journal of Political Economy, 70: 538-555 (1962).

[7] Ulman, Lloyd, "Labor Mobility and the Industrial Wage Structure in the Postward United States," Quarterly Journal of Economics, 79: 73-97 (1965).

[8] Wallis, Kenneth F., "Description of a Computer Program for Spectral Analysis of Economic Time Series," mimeographed paper, (November 5, 1965).

[9] Wold, H. O., "Review of Granger and Hatanaka, Spectral Analysis of Economic Time Series," Annals of Mathematical Statistics, 38: 288-293 (1967).