CHAPTER TEN

Data Analysis 2: Real Economic Variables

As has been mentioned, the change from examining prices to examining production, innovation, and other economic variables is not a straightforward one. The nature of the data used in the analysis changes in two ways. First, very few data are available for preindustrial times; and second, the quality of data even in industrial times is lower than for price data. For production data most of the period since the late eighteenth century is covered by time series of reasonable quality for the major core countries. But for the other economic variables only scattered series of mixed quality are available. These series are eclectic, consisting of a scattering of particular variables, countries, and time periods that in no way "cover" any class of variable. A correlation with long waves can provide only fragmentary evidence; and a lack of correlation may merely reflect the low quality of the data.

Thus the conclusions throughout this chapter must be more tentative than those in the previous chapter, and the conclusions regarding economic variables other than production and prices must be considered preliminary at best. Nonetheless, these tentative results offer little bits of evidence—clues if you will—regarding some of the other economic variables thought by various schools to play a role in long waves.

Production

Phase Period Growth Rates

To analyze the ten production series I first estimated the growth rates for each phase period of the base dating scheme (table 10.1).[1]

The ten production series begin with four series at the "world" level of analysis. Two series cover world industrial production: the first (1740–1850) is from Haustein and Neuwirth (who cite Hoffman); the second and later series (1850–1975) is from Kuczynski. In addition to his world industrial production series, Kuczynski gives series for world agricultural production and world total production (the third and fourth series). World industrial production before 1850 does not follow the long

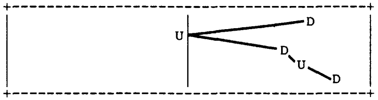
1. Note that the few data points after 1968 are not included on this table, since I had not yet changed the last turning point from 1968 to 1980. The 1940–80 phase ends in 1967.

Table 10.1. Production -- Growth Rates by Phase

World Industrial Production [Series 1]

Period	N	Mean	Gr.Rate
D 1720-1746	7	105.4	.027
U 1747-1761	15	124.8	-.001
D 1762-1789	28	163.3	.021
U 1790-1813	24	340.5	.026
D 1814-1847	34	837.5	.034

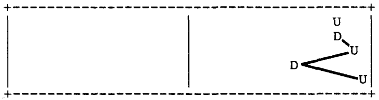
Average Annual Growth Rate
< -.040 .000 +.040 >



World Industrial Production [Series 2]

Period	N	Mean	Gr.Rate
U 1848-1871	22	166.7	.034
D 1872-1892	21	340.4	.035
U 1893-1916	24	800.0	.037
D 1917-1939	23	1350.6	.024
U 1940-1967	28*	3615.3	.040

Average Annual Growth Rate
< -.040 .000 +.040 >



World Agricultural Production

Period	N	Mean	Gr.Rate
U 1848-1871	22	116.5	.016
D 1872-1892	21	184.6	.021
U 1893-1916	24	290.2	.017
D 1917-1939	23	429.5	.022
U 1940-1980	36	648.9	.021

Average Annual Growth Rate
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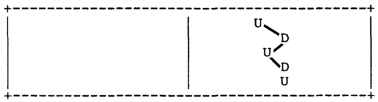
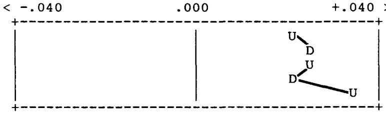


World Total Production

Period	N	Mean	Gr.Rate
U 1848-1871	22	128.3	.021
D 1872-1892	21	222.3	.026
U 1893-1916	24	414.5	.027
D 1917-1939	23	655.7	.022
U 1940-1980	36	1563.2	.036

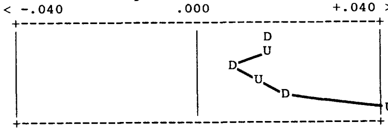
Average Annual Growth Rate
< -.040 .000 +.040 >



French Real Gross National Product

Period	N	Mean	Gr.Rate
D 1814-1847	28	127.1	.016
U 1848-1871	24	190.7	.015
D 1872-1892	21	252.9	.009
U 1893-1916	24	340.7	.014
D 1917-1939	23	439.3	.020
U 1940-1967	28*	724.0	.054

Average Annual Growth Rate
< -.040 .000 +.040 >

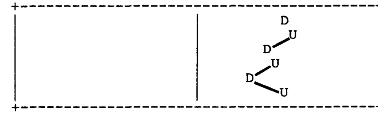


See notes to Table 9.1.

British Real Gross National Product

Period	N	Mean	Gr.Rate
D 1814-1847	18	122.0	.020
U 1848-1871	24	193.3	.022
D 1872-1892	21	314.4	.017
U 1893-1916	24	483.8	.018
D 1917-1939	23	585.9	.012
U 1940-1967	28*	987.2	.020

Average Annual Growth Rate
< -.040 .000 +.040 >



U.S. Real Gross National Product

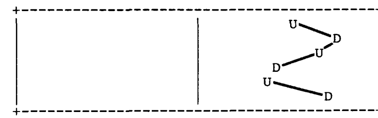
Period	N	Mean	Gr.Rate
U 1893-1916	24	194.9	.038
D 1917-1939	23	344.9	.013
U 1940-1980	28	867.3	.032

Average Annual Growth Rate
< -.040 .000 +.040 >

British Industrial Production

Period	N	Mean	Gr.Rate
U 1790-1813	13	117.0	.021
D 1814-1847	34	237.3	.032
U 1848-1871	24	582.7	.029
D 1872-1892	21	1003.9	.018
U 1893-1916	24	1568.6	.016
D 1917-1939	22	2228.4	.030

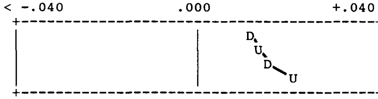
Average Annual Growth Rate
< -.040 .000 +.040 >



French Industrial Production

Period	N	Mean	Gr.Rate
D 1814-1847	33	119.6	.013
U 1848-1871	24	194.9	.014
D 1872-1892	21	270.4	.016
U 1893-1916	21	386.3	.023

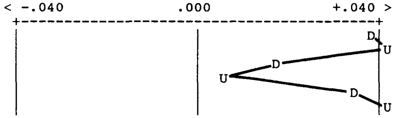
Average Annual Growth Rate
< -.040 .000 +.040 >



Belgian Industrial Production

Period	N	Mean	Gr.Rate
D 1814-1847	8	102.8	.040
U 1848-1871	24	219.3	.043
D 1872-1892	21	434.3	.019
U 1893-1916	24	704.2	.006
D 1917-1939	23	955.2	.035
U 1940-1967	28*	1556.7	.047

Average Annual Growth Rate
< -.040 .000 +.040 >



wave pattern of upswings and downswings. Since 1850, or at least from 1893 on, the pattern matches, but this is only a short period and does not justify any broad conclusions. World agricultural production seems to follow a pattern of inverse correlation with the nominal phase periods. This supports the hypothesis:

Downswings in agriculture correspond with general upswings. [A] (Ehrensaft)[2]

However, this corroboration is weak, since the differences in growth rates are slight (growth rates always remain between .016 and .022) and since only one series is analyzed. The series for world total production (industrial plus agricultural) does not match the long wave phases.[3]

The next three series measure real gross national product (GNP) for France, Britain, and the United States, respectively. The French GNP follows the long wave phase datings only weakly (due to strong growth in the 1917–39 nominal downswing).[4] British GNP follows the long wave pattern. The differences between the upswing and downswing phases, however, are slight (growth rates ranging from .012 to .020). The U.S. GNP series fits the long wave phases; but only one-and-a-half cycles (seventy-five years) of data are available.

The last three production series measure the volume of British, French, and Belgian industrial production, respectively. In none of these series do the growth rates correlate with the long wave phases.

To summarize, the estimated growth rates by phase period match the long wave phases rather weakly[5] for national GNP series and not at all for world production series and national indexes of industrial production. For production variables taken as a class (ten series), a correlation with long wave dating cannot be corroborated. In the results of t-tests on the growth rates of the production series (twenty-two to twenty-five pairs of phase periods), the sign of t in each of the two tests was as expected, but in neither case was t statistically significant (table 10.2).[6]

Lagged Correlations: Production

In the lag structures for production series, a striking pattern appears repeatedly (though not in every case). For the majority of series (and those with greatest

2. "Agriculture entered a B-phase as the economy as a whole entered an A . . . phase" (Ehrensaft 1980:77). Note that Ehrensaft considered only the most recent upswing.

3. This is not surprising, given the weak correlation in world industrial production and the inverse correlation in world agricultural production.

4. Problems could arise from the particular datings of the 1917 and 1940 turning points during wars that caused substantial fluctuations in French GNP.

5. Less consistently and with smaller variations in growth rates across phase periods than the price series.

6. As with the price t-tests, the 1968 turning point is used here rather than 1980. Since 1968 is presumed to be closer to the actual production turning point, using the 1980 date would only make this insignificant t-test slightly less significant.

Table 10.2. T-test Results for Ten Production Series

Variable	Period	Pairs[a]	Mean Growth 1st	2d	Rate[b] Diff.	DF[c]	t	Probability[d]
Production	1740-1975	Down/Up	.022	.025	.003	21	1.35	.096 –
		Up/Down	.025	.025	.000	24	-0.08	.468 –

a. Paired phases: D/U = Downswing with following upswing; U/D = upswing with following downswing.

b. 1st = average growth rate for 1st phase in pair; 2d = average growth rate for 2d phase in pair; Diff. = difference in growth rates (2d phase minus 1st). (Differences may show discrepancy due to rounding.)

c. DF = Degrees of freedom = number of phase period pairs minus 1.

d. 1-tailed probability (D/U positive; U/D negative as hypothesized).

– indicates not statistically significant.

robustness in their lag structures), the lag structure peaks *lead* the base dating scheme (and hence prices) by about ten to fifteen years (or one-fourth of a cycle) on average.

In the case of the two world industrial production series, both lag structures are fairly robust and peak around ten to fifteen years before the zero (fig. 10.1).[7] The fact that the patterns in these two series are so similar is a powerful corroboration of a lagged correlation in production, because the series cover two different periods of time (1740–1850 and 1850–1975, respectively) and come from two different sources affiliated with different long wave schools.[8] It is also noteworthy that the correlation emerges most clearly in these "world" (rather than national) series.

Other production series showing a similar pattern include World total production (1850–1975), British real GNP (1830–1975), U.S. real GNP (1889–1970), British industrial production (1801–1938), French industrial production (1815–1913) and Belgian industrial production (1840–1975):[9]

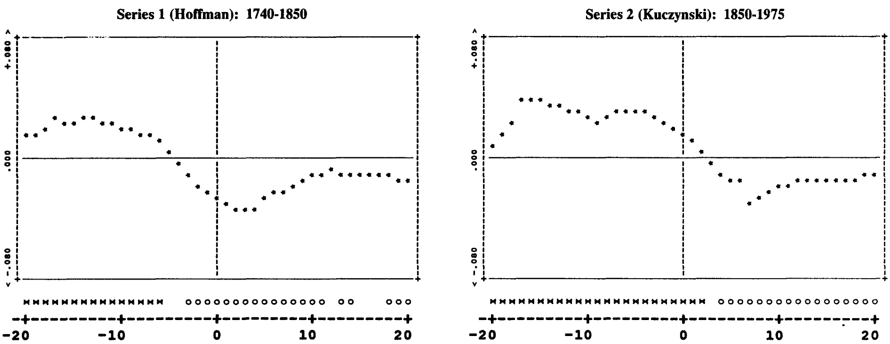
Series	Approximate Peak	"X" Region
World industrial production 1	−15	−20 to −6
World industrial production 2	−16	−20 to +2
World total production	−18	−20 to −1 except −9 to −7
British real GNP	−5	−19 to +2
U.S. real GNP	−4	−18 to +4
British industrial production	−9	−20 to −5
French industrial production	−19	−7 to −3
Belgian industrial production	−17	−10 to +15? (interspersed)

7. For the two series the peaks are at −17 to −13 lags, and −17 to −15 lags, respectively.

8. The 1740–1850 series is from non-Marxists—Hoffman, reprinted by Haustein and Neuwirth (1982:76). The 1850–1975 series is from a Marxist, Kuczynski (1980:309).

9. The last two series are less robust than the others.

Figure 10.1. Lag Structures, World Industrial Production



By contrast, two production series showed both less robustness and a different lag structure. First, French real GNP peaks at about +7 lags.[10] Second, world agricultural production seems to be out of phase with world industrial production, with a trough at about −8 lags and a peak around +15 ("O" region, −13 to +2). This inverse correlation, mentioned above, appears to be robust, although the difference between the peak and trough of the lag structure is small.

For the production variables as a class, then, lag structures for eight of the ten series show production leading the base dating scheme and hence leading prices by about ten to fifteen years on average.[11] Agricultural production, by contrast, follows an inverse correlation with the long wave.[12] I therefore reconceptualized production as leading prices by ten to fifteen years and adopted a dating scheme for production that is shifted from the base dating. How does this affect the overall strength of long waves in this class of variable as reflected in the pattern of alternating growth rates and in the t-test?

I reestimated the growth rates for the ten production series first with −10 years and then with −15 years shift in the base dating scheme.[13] In production growth rates with the −15-year time shift, the alternating pattern in successive phases is now visible in the world industrial production indexes, world total production, United States GNP, and (less strongly) in British and French industrial production—but not in the other four production series (table 10.3). The pattern was similar in the estimates using a −10-year dating shift (not shown here).

10. The lag structure stays at a high positive level, however, for an extended "X" region from −20 to +13 lags (except 0). Thus it is not entirely inconsistent with the behavior of the first six production series, which lead the base dating scheme.

11. Six of these eight are fairly robust against time shifts, while the other two are less robust. A ninth series is also less robust but not entirely inconsistent.

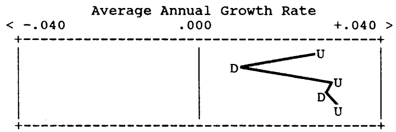
12. The hypothesis that agricultural production downswings correspond with general upswings, if accepted, would imply that agricultural production does not really belong in this class of variables. But it would be too "ad hoc" to draw such a conclusion on the basis of one time series. Thus for purposes of testing the class of production variables as a whole, I have retained the agricultural production series.

13. In lagging a class of variables, I have used only five-year increments (e.g., −5 lags, −10 lags, etc.) in the time shifts (see chap. 8).

Table 10.3. Production -- Growth with Phases Shifted

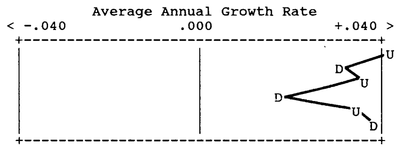
World Industrial Production [Series 1] Time Shift -15

Period	N	Mean	Gr.Rate
U 1732-1746	7	105.4	.027
D 1747-1774	28	132.7	.009
U 1775-1798	24	213.5	.032
D 1799-1832	34	513.0	.028
U 1833-1856	18	1179.9	.031



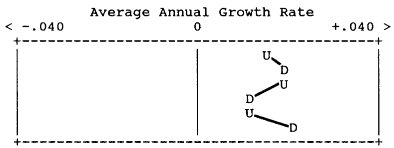
World Industrial Production [Series 2] Time Shift -15

Period	N	Mean	Gr.Rate
U 1833-1856	7	127.2	.069
D 1857-1877	21	207.2	.033
U 1878-1901	24	448.0	.038
D 1902-1924	23	987.4	.018
U 1925-1965	41	2701.7	.036
D 1966-1975	10	7724.8	.040



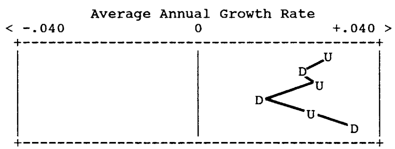
World Agricultural Production Time Shift -15

Period	N	Mean	Gr.Rate
U 1833-1856	7	103.9	.015
D 1857-1877	21	131.4	.021
U 1878-1901	24	216.8	.020
D 1902-1924	23	325.8	.011
U 1925-1965	41	536.7	.012
D 1966-1975	10	845.9	.022



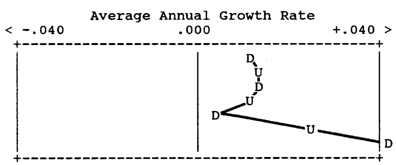
World Total Production Time Shift -15

Period	N	Mean	Gr.Rate
U 1833-1856	7	109.4	.029
D 1857-1877	21	149.3	.025
U 1878-1901	24	272.9	.027
D 1902-1924	23	488.2	.015
U 1925-1965	41	1045.9	.026
D 1966-1975	10	2423.4	.036



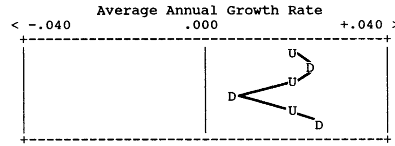
French Real Gross National Product Time Shift -15

Period	N	Mean	Gr.Rate
D 1799-1832	13	112.1	.012
U 1833-1856	24	150.1	.015
D 1857-1877	21	214.4	.013
U 1878-1901	24	276.3	.013
D 1902-1924	23	360.9	.004
U 1925-1965	41	606.0	.027
D 1966-1975	10	1647.2	.049



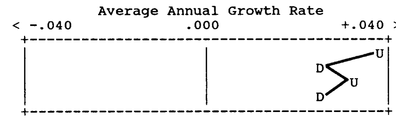
British Real Gross National Product Time Shift -15

Period	N	Mean	Gr.Rate
U 1833-1856	24	139.3	.021
D 1857-1877	21	230.8	.025
U 1878-1901	24	363.8	.021
D 1902-1924	23	526.3	.006
U 1925-1965	41	832.5	.020
D 1966-1975	10	1507.9	.026



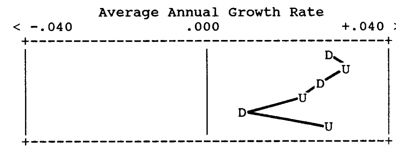
U.S. Real Gross National Product Time Shift -15

Period	N	Mean	Gr.Rate
U 1878-1901	13	129.7	.040
D 1902-1924	23	253.9	.026
U 1925-1965	41	660.9	.034
D 1966-1975	5	1420.8	.026



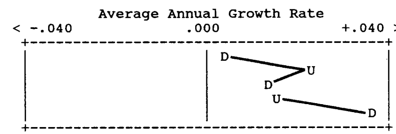
British Industrial Production Time Shift -15

Period	N	Mean	Gr.Rate
D 1799-1832	32	154.2	.028
U 1833-1856	24	365.1	.032
D 1857-1877	21	722.0	.027
U 1878-1901	24	1174.9	.023
D 1902-1924	23	1710.8	.007
U 1925-1965	14	2494.1	.029



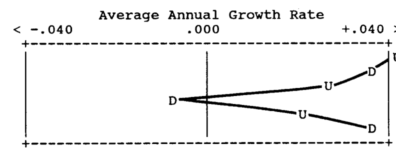
French Industrial Production Time Shift -15

Period	N	Mean	Gr.Rate
D 1799-1832	18	107.7	.004
U 1833-1856	24	149.7	.024
D 1857-1877	21	216.1	.013
U 1878-1901	24	304.5	.016
D 1902-1924	12	419.7	.037



Belgian Industrial Production Time Shift -15

Period	N	Mean	Gr.Rate
U 1833-1856	17	129.2	.049
D 1857-1877	21	293.8	.037
U 1878-1901	24	525.3	.027
D 1902-1924	23	705.9	-.007
U 1925-1965	41	1349.0	.023
D 1966-1975	10	3091.2	.037



See notes to Table 9.1.

Table 10.4. T-test Results for Production with Phases Shifted

Variable	Lag	Pairs[a]	Mean Growth Rate[b] 1st	2d	Diff.	DF[c]	t	Probability[d]
Production	-10	Down/Up	.021	.028	.007	21	3.03	.003 **
		Up/Down	.028	.023	-.005	24	2.12	.022 *
Production	-15	Down/Up	.017	.025	.008	20	3.43	.002 **
		Up/Down	.027	.022	-.005	25	-1.70	.050 –

Note: All production series, 1740-1975, are included.
a. Paired phases: D/U = Downswing with following upswing; U/D = upswing with following downswing.
b. 1st = average growth rate for 1st phase in pair; 2d = average growth rate for 2d phase in pair; Diff. = difference in growth rates (2d phase minus 1st). (Differences may show discrepancy due to rounding.)
c. DF = Degrees of freedom = number of phase period pairs minus 1.
d. 1-tailed probability (D/U positive; U/D negative as hypothesized).
** indicates statistical significance level below .01;
* indicates statistical significance level below .05;
– indicates not statistically significant.

In the t-tests for the production series growth rates using dating schemes shifted –10 and –15 years, the signs of the growth rate differences are as expected (table 10.4). For the –10 year shift, the difference is statistically significant at the .01 level for D/U pairs and at .05 for U/D pairs. For the –15 year shift, the difference is significant at .01 for the D/U pairs and not quite significant for the U/D pairs. Overall, I conclude that the production series fit rather well to a shifted long wave pattern that leads prices by ten to fifteen years.

Thus I accept the hypotheses that long waves exist in production as well as prices and that production leads prices:

Long waves exist in prices, production, and investment. [A]
(Kondratieff, Mandel, Kuczynski, Gordon, Kleinknecht, Delbeke, Van Duijn, Forrester)

Long waves exist in prices only, not in production and investment. [R]
(Kuznets, Silberling, Cleary and Hobbs, Van Ewijk, Van der Zwan)

Production increases precede price increases. [A]
(Imbert)

Production phases are synchronous with price phases. [R]
(Most long wave researchers)

Stagflation: A New Interpretation

The lag between long waves in production and those in prices opens the way to resolving a central anomaly and dispute in the long wave literature—the stagflation of the 1970s. Mandel argues that production began a downswing around 1968; Rostow argues that prices rose rapidly through the 1970s. Both are correct if production leads prices—a production peak around 1968 would go with a price peak around 1980.

Furthermore, if production leads prices, then the dates in the base dating scheme must be reconsidered. Braudel's dates seem to derive from prices (see chapter 4). Frank's dates claim to describe rapid and slower development, but since they are from preindustrial times it must be assumed that price data also played a large role there (since few data other than prices are available in that era). Kondratieff's dates, too, fit best for his price data and less well for production data. Only Mandel's turning points seem to be truly based on production.

I therefore changed the last date in the dating scheme to reflect a new understanding of the production-price lag, making the base dating consistent and resolving the stagflation problem. The peak of 1968 was changed to 1980, representing a price peak ending an unusually long upswing from 1940. The base dating scheme is then explicitly a dating of prices.

I chose 1980 as the best date for this peak for several reasons. First, if 1968 is the production peak (following Mandel), then the price peak should be about ten to fifteen years later. Second, inflation did in fact subside in the United States in the 1980s. Third, the change in U.S. inflation seems to come just after 1980:

Annual percentage change			
Producer prices[14]		Consumer prices[15]	
1978–79	12.6%	1980	12.4%
1979–80	14.1%	1981	8.9%
1980–81	9.2%	1982	3.9%
1981–82	2.0%	1983	3.8%
		1984	4.0%
		1985	3.8%

The stagflation of the 1970s, then, becomes not an anomaly but only a particularly strong instance of a phenomenon that may often mark the late upswing phase.[16] The previous historical instance was the hyperinflation following World War I, in the early 1920s. In the instance before that, Dupriez (1978:203) sees a similar pattern around 1872. And the instance before that, around 1815, is discussed by Mokyr and Savin (1976) explicitly as a case of "stagflation."

14. Annual percentage change in the producer price index for major commodity groups from U.S. Census (1983:486).

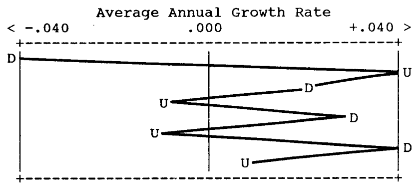
15. Bureau of Labor Statistics, reprinted in *Boston Globe*, Jan. 23, 1986, p. 19.

16. Often associated with war; see chap. 11.

Table 10.5. Innovation -- Growth Rates by Phase

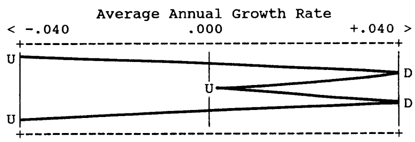
List of Innovations [Haustein & Neuwirth]

Period	N	Mean	Gr.Rate
D 1762-1789	26	.1	-.062
U 1790-1813	24	.2	.052
D 1814-1847	34	.6	.022
U 1848-1871	24	.8	-.009
D 1872-1892	21	1.7	.031
U 1893-1916	24	1.0	-.012
D 1917-1939	23	1.3	.078
U 1940-1980	28	1.3	.007



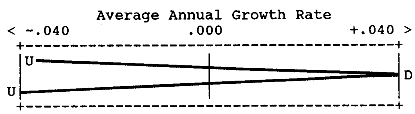
List of Innovations [Van Duijn]

Period	N	Mean	Gr.Rate
U 1848-1871	16	.3	-.080
D 1872-1892	21	.5	.069
U 1893-1916	24	.5	.001
D 1917-1939	23	1.0	.046
U 1940-1980	28	.9	-.048



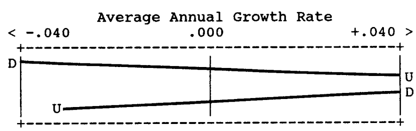
List of Innovations [Clark et al]

Period	N	Mean	Gr.Rate
U 1893-1916	13	.5	-.041
D 1917-1939	23	1.1	.087
U 1940-1980	28	1.0	-.063



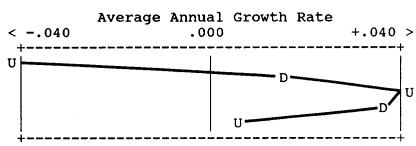
List of "Product" Innovations [Kleinknecht]

Period	N	Mean	Gr.Rate
D 1872-1892	14	.3	-.138
U 1893-1916	24	0.0	.094
D 1917-1939	23	.9	.093
U 1940-1980	26	.5	-.033



List of "Improvement" Innovations [Kleinknecht]

Period	N	Mean	Gr.Rate
U 1848-1871	13	.3	-.071
D 1872-1892	21	.4	.015
U 1893-1916	24	.4	.058
D 1917-1939	23	.3	.038
U 1940-1980	28	.6	.007



See notes to Table 9.1.

Innovation and Invention

The next five series derive from lists of innovations.[17] The first four are counts of basic innovations, while the fifth is of "improvement" innovations in contrast to basic innovations.[18]

In the estimated growth rates for the innovation series, the first (Haustein and Neuwirth) matches the long wave base dating scheme phases (inversely) only after

17. Four of these I transformed into time series (one was already a time series).

18. Kleinknecht claims that only product innovations, not improvement innovations, cluster on the downswing phases.

Table 10.6. Innovation -- Changes in Mean Levels

Haustein and Neuwirth's data:		Kleinknecht's data—"product" innovations:	
Mean change U/D:[a]	.4 .9 .3	Mean change U/D:	.9
Mean change D/U:[b]	.1 .2 -.7 0	Mean change D/U:	-.3 -.4
Van Duijn's data:		Kleinknecht's data—"improvement" innovations:	
Mean change U/D:	.2 .5	Mean change U/D:	.1 -.1
Mean change D/U:	0 -.1	Mean change D/U:	0 .3
Clark, Freeman and Soete's data:			
Mean change U/D:	.6		
Mean change D/U :	-.1		

a. Change in mean level from upswing to downswing, calculated from table 10.5.
b. Change in mean level from downswing to upswing.

1815 (table 10.5).[19] The next two series (Van Duijn; Clark, Freeman, and Soete) consistently fit the phase periods (again inversely). The final two innovation series—Kleinknecht's lists of "product" (basic) and "improvement" (non-basic) innovations—show no long wave pattern.

As discussed in chapter 8, some confusion exists about whether the correlation hypothesized for innovation is for levels (clusters) or for growth rates.[20] Therefore, for these series I tabulated changes in mean *levels* (for each phase period) from one phase period to the next (table 10.6), in addition to analyzing the estimated growth rates.[21] For Haustein and Neuwirth's data, the levels correlate (inversely) with phases more closely than did the growth rates for the same series.[22] For Van Duijn's and Clark, Freeman, and Soete's data, the levels match the long wave phases (inversely), as had the growth rates. And Kleinknecht's data for "product" (but not "improvement") innovations also matched long wave phases more strongly in the analysis of levels than of growth rates.

To summarize, the growth rate estimates within phase periods fit the long wave pattern, inversely, in only two of the four basic innovation series. The innovation levels, however, fit the base dating inversely for the same two basic innovations

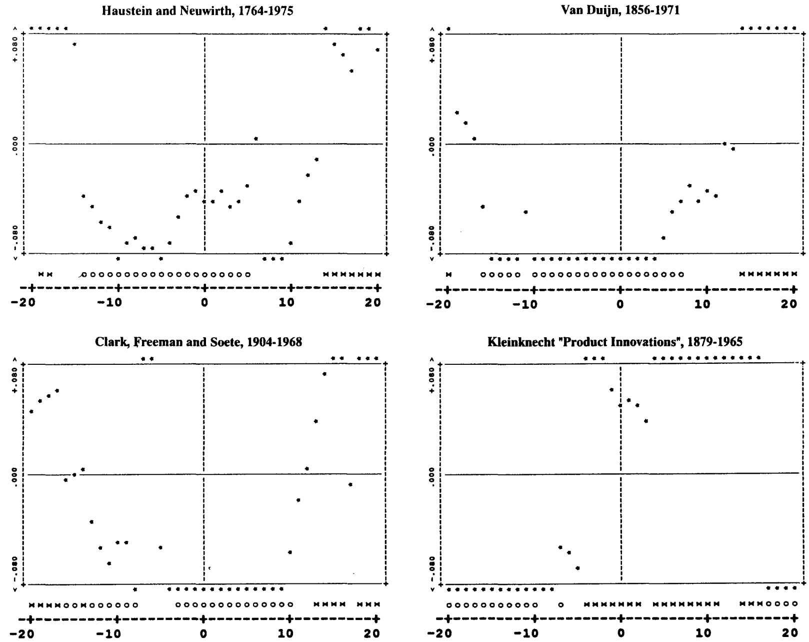
19. The last eight years of data for this series, 1968–75, are omitted as in table 10.1 (see note 1, above). A 1968–75 phase is included in the t-test results below, but including it in the 1940–80 phase would actually strengthen the significance of t slightly.

20. The innovation series are counts of discrete events, and for some hypotheses it is the rate of *occurrence* (not of growth) that differs on upswing and downswing phases.

21. The numbers shown are the changes in mean levels for each phase period (calculated directly from table 10.5).

22. The changes in mean levels indicate that while the average annual number of innovations grew over time, the annual number during *downswings* registered the biggest increases compared with the previous upswings.

Figure 10.2. Lag Structures, Four Innovation Series



series and (more weakly) for the other two basic innovation series.[23] For the "improvement" innovation series, no fit to the long wave was found. These results, although limited and tentative, are consistent with the hypothesis that basic innovations cluster on the downswing phase of the long wave.

As shown in chapter 8, to say that levels correlate with long wave phases is equivalent to saying that growth rates lead the nominal phases by about one-fourth of a cycle (ten to fifteen years). These leads should be evident in the lag structures for innovation growth rates. Since the correlation is inverse, we should look for a trough in the lag structure leading the base dating.

The lag structures for the four basic innovation series (fig. 10.2) do in fact indicate such a pattern, but with less than one-fourth of a cycle of lead. The pattern is rather weak, and the lag structures are not very robust against time shifts.[24] But the "O" regions and troughs are shifted to the left of zero for all four series (this similarity is important since the series come from four different data sources).

23. Secular growth in these two series made the correlation weaker, but the means on downswings were *higher* above the mean of the previous upswing than vice versa.

24. Part of the problem with these series may be their lack of fine structure—each year is either a zero or a very small integer according to whether any innovations on a limited list are dated in that year. It is difficult to estimate growth rates in such a series, and one must be very cautious in interpreting the results.

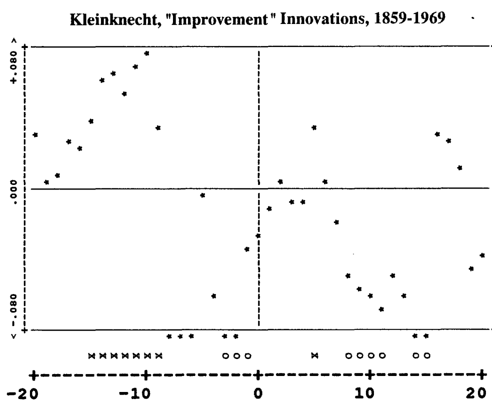
Series	"O" Region	Best
List of innovations [Haustein and Neuwirth] (1764–1975)	−14 to +5	−5
List of innovations [Van Duijn] (1856–1971)	−16 to +7	−4
List of innovations [Clark et al] (1904–1968)	−16 to +10	0
List of "product" innovations [Kleinknecht] (1879–1965)	−20 to −7	−19?
List of "improvement" innovations [Kleinknecht] (1859–1969)	+8 to +15?	+15?

For Haustein and Neuwirth's series, there is a discernable inverted pattern with a trough at −5 lags.[25] For Van Duijn's list of innovations, the inverted wave is the most strongly defined of all the innovation series, while the lag structure for Clark et al.'s innovation list is more jumpy. Kleinknecht's list of "product" innovations is not robust against time shifts, but from the "O" and "X" regions it appears to show a trough at about −19 lags and a peak around +14.[26]

The last innovation series, Kleinknecht's "improvement" innovations, has "X" and "O" regions interspersed, with very low robustness (fig. 10.3). But there is a discernible peak around −10 lags and a trough around +15, which is consistent with Kleinknecht's hypothesis that "improvement" innovations cluster at a point opposite on the long wave to "basic" innovations.

I grouped the four innovation series together as a class of variables[27] and tested time shifts of −5 and −10 years in the base dating scheme for this class. In the −5-year shift (table 10.7), the alternation of upswing and downswing periods matches

Figure 10.3. Lag Structure, "Improvement" Innovations



25. There is a (deeper) trough at +7 lags, but it is not stable with respect to minor time shifts (+6 lags gives an opposite correlation).

26. This is somewhat phase-shifted as compared with the previous three series, perhaps reflecting Kleinknecht's different criteria in distinguishing types of innovations. The long lead in this series would explain why it correlated only in terms of levels, and not at all when measured by growth rates, in the analysis above.

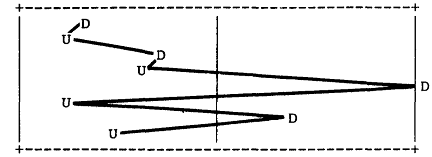
27. Excluding the "improvement innovations" series hypothesized to *not* correlate with the other innovations.

Table 10.7. Innovation -- Growth with Phases Shifted

List of Innovations [Haustein & Neuwirth] **Time Shift -5**

Average Annual Growth Rate
< -.040 .000 +.040 >

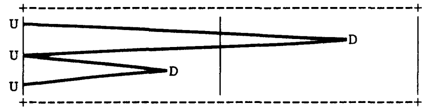
Period	N	Mean	Gr.Rate
D 1757-1784	21	.1	-.027
U 1785-1808	24	.1	-.031
D 1809-1842	34	.5	-.013
U 1843-1866	24	.9	-.015
D 1867-1887	21	1.5	.086
U 1888-1911	24	1.0	-.032
D 1912-1934	23	.9	.016
U 1935-1975	41	1.4	-.021



List of Innovations [Van Duijn] **Time Shift -5**

Average Annual Growth Rate
< -.040 .000 +.040 >

Period	N	Mean	Gr.Rate
U 1843-1866	11	.4	-.125
D 1867-1887	21	.3	.027
U 1888-1911	24	.6	-.074
D 1912-1934	23	.8	-.010
U 1935-1975	37	1.0	-.051



List of Innovations [Clark et al] **Time Shift -5**

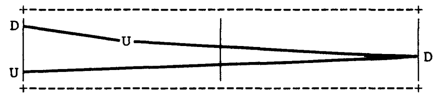
Average Annual Growth Rate
< -.040 .000 +.040 >

Period	N	Mean	Gr.Rate
U 1888-1911	8	.6	.133
D 1912-1934	23	.7	.067
U 1935-1975	34	1.2	-.056

List of "Product" Innovations [Kleinknecht] **Time Shift -5**

Average Annual Growth Rate
< -.040 .000 +.040 >

Period	N	Mean	Gr.Rate
D 1867-1887	9	.3	-.200
U 1888-1911	24	.1	-.021
D 1912-1934	23	.4	.071
U 1935-1975	31	.8	-.067



See notes to Table 9.1.

changes in the growth rates in all but two phase periods.[28] For the −10-year shift, the results were not as consistent.

In the t-tests for this class of series, with lags of 0, −5, and −10 years, the number of cases (pairs of phase periods) is only eight or nine for each test (table 10.8). In all cases the sign of t indicates an inverse correlation to the base dating but is not statistically significant. The lags of both −5 and −10 years are better than the unlagged case, and the lag of −5 years is closer to being significant than is the lag of −10 years. The lack of significance is not of great concern given the few degrees of freedom and the jumpy character of the original time series.[29] What I find more important is the consistency of results across four different data sources and the fact that the lag of −5 years gives the strongest correlation.

28. Both of them "end" phases of the series with less than ten years' data.

29. The series consisted of zeroes and small integers. I constructed three of the four series from simple lists of innovations and their dates.

Table 10.8. T-test Results for Four Innovation Series

Time Shifts of 0, -5, and -10 Years

Variable	Lag	Pairs[a]	Mean Growth Rate[b] 1st	2d	Diff.	DF[c]	t	Probability[d]
Innovation	0	Down/Up	.025	-.001	-.026	8	-0.64	.536 –
		Up/Down	.002	.026	.025	7	0.61	.564 –
Innovation	-5	Down/Up	.002	-.041	-.043	8	-1.31	.227 –
		Up/Down	-.024	.035	.058	6	2.23	.068 –
Innovation	-10	Down/Up	.021	-.028	-.049	7	-2.18	.066 –
		Up/Down	-.048	-.019	.030	6	0.42	.692 –

Note: Four innovation series, 1764-1975, are included.

a. Paired phases: D/U = Downswing with following upswing; U/D = upswing with following downswing.

b. 1st = average growth rate for 1st phase in pair; 2d = average growth rate for 2d phase in pair; Diff. = difference in growth rates (2d phase minus 1st). (Differences may show discrepancy due to rounding.)

c. DF = Degrees of freedom = number of phase period pairs minus 1.

d. 2-tailed probability (Either direction of correlation hypothesized).

– indicates not statistically significant.

Overall, I find the evidence most consistent with the hypothesis that long waves in innovation are inversely correlated with prices and production and lead prices by about five years.[30] Innovations hence follow production by five to ten years, which is consistent with the hypothesis that an upturn in production tends to dampen innovation, while a downturn in production stimulates innovation. Thus I sort out the innovation hypotheses as follows:

Innovations cluster at one point on the long wave. [A]
(Kondratieff, Mensch, Freeman, Forrester, Mandel, Gordon)

- -

Innovations do not occur in clusters. [R]
(Kuznets)

Innovations cluster late in the downswing. [A]
(Gordon, Schumpeter)

Innovations cluster on the downswing. [A]
(Mensch)

Innovations are fewer late in the upswing. [A]
(Forrester)

- -

30. The inverted five-year lead in growth rates means that innovations *cluster* at the end of the nominal downswing phase.

Innovations cluster early in the upswing. [R]
(Kondratieff, Mandel, Freeman et al.)

''Product'' innovations cluster early in the upswing. [R]
(Van Duijn)

Innovations are fewer late in the downswing. [R]
(Freeman et al.)

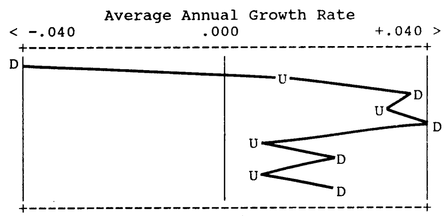
Invention

Invention is hypothesized by some researchers to correlate with the long wave, but perhaps with a different timing from innovation. One British and three U.S. annual patent series were examined (table 10.9). The results are anomalous in that *British* patents appear inversely correlated with the long wave (patents increasing more

Table 10.9: Invention -- Growth Rates by Phase

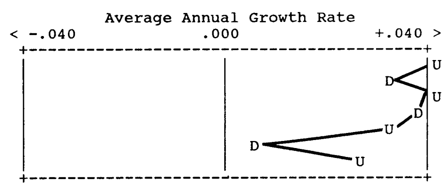
Number of British Patents

Period	N	Mean	Gr.Rate
D 1720-1746	9	4.8	-.042
U 1747-1761	15	9.8	.012
D 1762-1789	28	34.0	.039
U 1790-1813	24	85.1	.032
D 1814-1847	34	242.5	.054
U 1848-1871	24	480.7	.005
D 1872-1892	21	831.8	.023
U 1893-1916	24	1289.0	.006
D 1917-1939	19	1537.3	.025



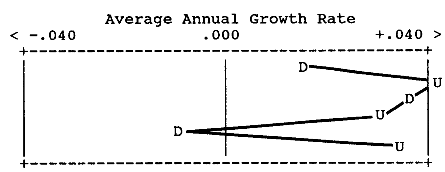
Number of U.S. Patents [Series 1]

Period	N	Mean	Gr.Rate
U 1790-1813	24	84.8	.111
D 1814-1847	34	394.1	.034
U 1848-1871	24	4870.6	.114
D 1872-1892	21	17446.9	.040
U 1893-1916	24	30238.3	.034
D 1917-1939	23	42343.3	.005
U 1940-1980	36	48372.4	.029



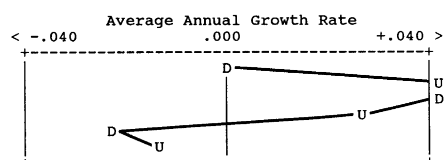
Number of U.S. Patents [Series 2]

Period	N	Mean	Gr.Rate
D 1814-1847	11	480.5	.015
U 1848-1871	24	4859.9	.114
D 1872-1892	21	17212.1	.038
U 1893-1916	24	32066.3	.031
D 1917-1939	23	44865.6	-.009
U 1940-1980	11	37860.6	.037



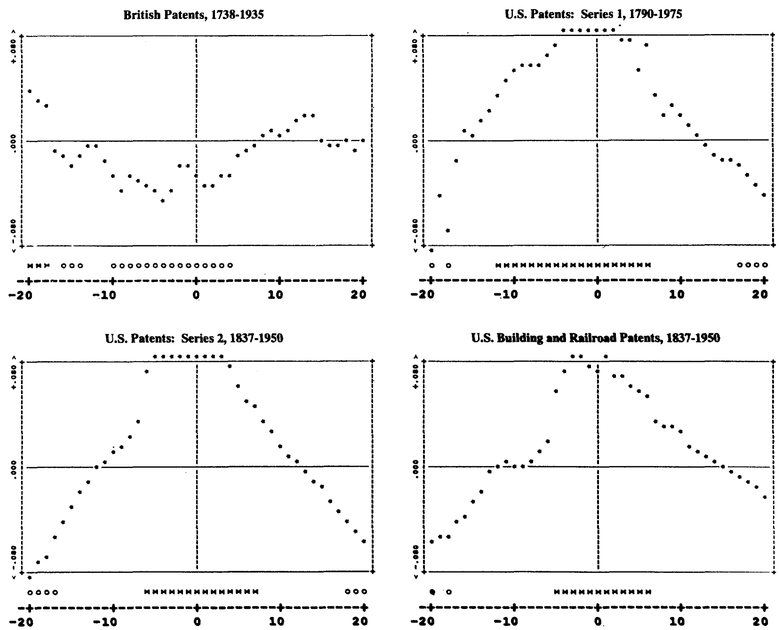
U.S. Patents in Building and Railroads

Period	N	Mean	Gr.Rate
D 1814-1847	11	16.8	-.001
U 1848-1871	24	174.8	.114
D 1872-1892	21	1071.7	.071
U 1893-1916	24	2069.7	.029
D 1917-1939	23	1656.3	-.024
U 1940-1980	11	792.3	-.013



See notes to Table 9.1.

Figure 10.4. Lag Structures, Four Invention Series



rapidly during downswings), while *U.S.* patents are directly correlated, though less consistently.[31]

The lag structures do not solve this anomaly (fig. 10.4). For the British series, there is a clear inverted pattern (of moderate robustness), with a trough around −4. But for all three U.S. patent series there is a clearer and quite robust lag structure peaking around 0 (and thus inverted as compared with British patents):

Series	"X"/"O" Region	Best
Number of British patents (1738–1935)	O −16 to +4	−4
U.S. patents in building and railroads (1837–1950)	X −5 to +6	−3
Number of U.S. patents (1790–1975)	X −12 to +6	−2
Number of U.S. patents (1837–1950)	X −6 to +7	0

The contrary behavior of British and U.S. patent series remains an anomaly; further investigation (perhaps encompassing more countries) would be useful.

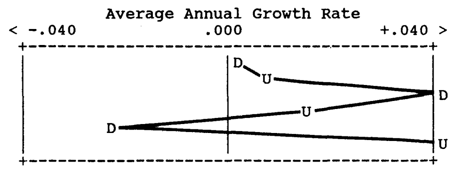
I did not run any t-tests on invention as a class, since the U.S. and British results would clearly just cancel each other out and since there is no theoretical basis for postulating an inverse timing in Britain from the United States.

31. The exception to the British pattern is the first period, which, however, contains only nine years of data. The growth rates are parallel in the three U.S. series (which cover the same time frame), and all three contain a deviant period, 1893–1916, of slackened growth on an upswing.

Table 10.10. Capital Investment -- Growth Rates by Phase

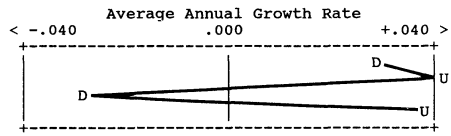
U.S. Private Building Volume

Period	N	Mean	Gr.Rate
D 1814-1847	18	213.5	.001
U 1848-1871	24	537.2	.007
D 1872-1892	21	897.2	.062
U 1893-1916	24	1428.0	.017
D 1917-1939	23	1072.4	-.025
U 1940-1980	18	1536.4	.082



U.S. Railroad Gross Capital Investment

Period	N	Mean	Gr.Rate
D 1872-1892	21	69.6	.029
U 1893-1916	24	88.4	.043
D 1917-1939	23	73.9	-.031
U 1940-1980	11	75.7	.040



See notes to Table 9.1.

Capital Investment

For capital investment, only two series were available, both of them for the U.S. and neither very central (see growth rates in table 10.10). United States private building volume does not fit the phase periods well. United States gross capital investment in the railroad industry, however, correlates strongly (and directly) with the long wave (although the series spans only two long waves). The data are too limited to draw any firm conclusions, and there are not enough data for a t-test.

The two capital investment series show somewhat similar lag structures, both with three somewhat ill-defined peaks around −17, −5, and +7 lags, respectively, and dropping off to a trough somewhere beyond +20 lags. The lag structures are not very robust but suggest that capital investment may lead the base dating by perhaps ten years (hence closely following production trends).[32] Shifting the two capital investment series by −5 years (leading prices) only slightly improved the resulting growth rates over the unlagged ones.

There are not nearly enough data to draw any firm conclusions about capital investment. But to the extent that the evidence supports any position, it is the hypothesis that long waves in capital investment lag production but lead prices:

Capital investment increases early in the upswing. [A]
(Kondratieff, Mandel, Gordon, Forrester)

Capital investment is low during the downswing. [A]
(Van Duijn)

- - - - - - - - - - - - - - - - - - - -

Capital investment increases on the downswing. [R]
(Hartman and Wheeler)

---

32. For U.S. private building volume, the "X" regions are from −20 (at least) to −14 lags, −9 to −3, and +5 to +8 lags, with the strongest peak coming in the first of these, around −18 lags. The subsequent

The analysis of capital investment on the long wave could be a fruitful area for future research.

Trade

The four trade series were an eclectic lot, consisting of: (1) the volume of Atlantic shipping at Seville in the earliest era, 1506–1650; (2) the net volume of British wheat exports, 1700–1775;[33] (3) English exports in current prices, 1700–1775;[34] and (4) Kuczynski's series for total world exports, 1850–1975. The four trade series do not correlate well with the long wave (table 10.11).[35] There are not enough data, and the four series are not comparable enough, to support a t-test for trade indicators.

The results of the lagged correlation analysis do not help much. The lag structure for Spanish trade (1506–1650) is quite nonrobust, with "X" and "O" regions interspersed. For British wheat trade (1700–1775), the lag structure is extremely time-sensitive around 0 and +14 lags.[36] For British exports (1700–1775), the lag structure is more robust and indicates a peak at around −8 lags. But since this series is in current prices, the degree of correlation is probably attributable to prices and not volume of trade. The lag structure for total world exports (1850–1975) shows a very long "X" region roughly in phase with the base dating scheme (−18 to +16, with peak around +6).[37]

To summarize, no consistent correlation is found in the trade series either for lagged or unlagged datings. I conclude that long waves cannot be identified in this group of series—either because long waves do not affect volumes of trade or because these very limited data are inadequate. Provisionally, I reject the trade hypothesis:

Long waves do not exist in trade. [A]
(Oparin, Van der Zwan, Van Ewijk)

Long waves exist in world trade. [R]
(Kondratieff, Mandel, Mauro, Kuczynski)

two peaks drop off toward the eventual trough at +20 lags or more. For U.S. railroad gross capital investment, the "X" regions correspond to the second and third peaks, −11 to +2 lags and +10 to +11 lags. The second peak, around −4 lags, is the strongest, while the third is much weaker, dropping off toward the trough beyond +20 lags.

33. The value is negative if imports exceed exports.

34. This is the only non-price series expressed in current rather than constant prices; hence any long waves found in this series might be just a by-product of price waves.

35. British wheat exports seem to show an inverse correlation, but the high volatility of this series makes me skeptical of any conclusion.

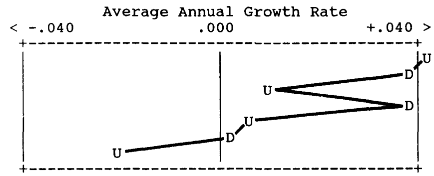
36. There is a possible inverse correlation, with the "O" region extending from 0 to +11 lags, and the trough around +7. This would mean that wheat exports begin declining (imports pick up) just after inflation picks up. But the results are only weakly suggestive of such a conclusion.

37. Mauro's (1964:313) datings of long waves in world trade lead the base dating scheme by only about one year.

Table 10.11. Trade -- Growth Rates by Phase

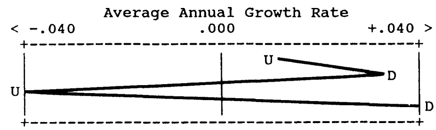
Volume of Seville-Atlantic Shipping

	Period	N	Mean	Gr.Rate
U	1509-1528	20	215.1	.043
D	1529-1538	10	374.1	.040
U	1539-1558	20	604.4	.010
D	1559-1574	16	767.4	.039
U	1575-1594	20	981.6	.007
D	1595-1620	26	1204.8	.002
U	1621-1649	29	878.0	-.021



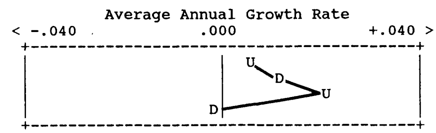
British Net Volume of Wheat Exports

	Period	N	Mean	Gr.Rate
U	1689-1719	20	213.9	.009
D	1720-1746	27	410.3	.036
U	1747-1761	15	734.0	-.085
D	1762-1789	14	-30.3	3.044



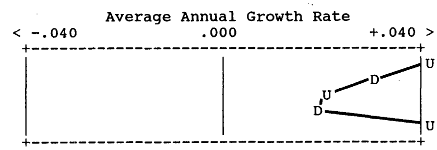
English Exports in Current Prices

	Period	N	Mean	Gr.Rate
U	1689-1719	20	106.3	.006
D	1720-1746	27	128.4	.012
U	1747-1761	15	203.5	.021
D	1762-1789	14	228.2	-.001



Total World Exports

	Period	N	Mean	Gr.Rate
U	1848-1871	22	183.2	.048
D	1872-1892	21	437.3	.032
U	1893-1916	24	804.7	.023
D	1917-1939	23	1126.9	.020
U	1940-1980	36	3280.4	.061



See notes to Table 9.1.

Real Wages

The final two time series measure real wages in England; the first for London alone (1700–1787), the second for South England (1736–1954). Growth rate estimates for both series, (table 10.12) match the long wave phase periods perfectly and inversely. This indicates that wages fail to keep pace with inflation during price upswing phases (hence real wages fall) but do not drop as fast as prices during downswings.[38]

The lag structures show the inverse correlation to be fairly robust, especially for the second, longer series. For the first wage index (London), the "O" region is from −6 to +15 lags, with the trough around −4 lags. For the second index (South England), the "O" region is from −15 to +8 lags, with the trough around −2.

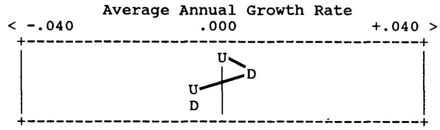
These results suggest that wage changes may *lead* price changes by a few years.

38. This inverse relationship is consistent with Braudel's observations for preindustrial times (see chap. 3).

Table 10.12. Real Wages -- Growth Rates by Phase

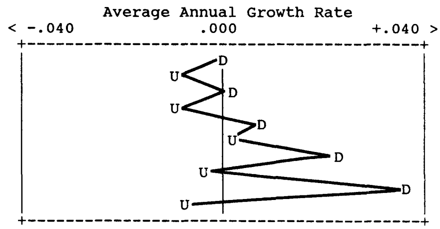
Real Wages for London

	Period	N	Mean	Gr.Rate
U	1689-1719	20	107.3	.001
D	1720-1746	27	119.8	.005
U	1747-1761	15	118.1	-.007
D	1762-1789	26	97.9	-.006



South English Real Wage Index

	Period	N	Mean	Gr.Rate
D	1720-1746	11	93.0	.001
U	1747-1761	15	87.6	-.011
D	1762-1789	28	76.7	.003
U	1790-1813	24	66.3	-.009
D	1814-1847	34	89.2	.008
U	1848-1871	24	105.1	.003
D	1872-1892	21	143.2	.024
U	1893-1916	24	175.2	-.005
D	1917-1939	23	269.1	.038
U	1940-1980	15	256.7	-.008



See notes to Table 9.1.

However, the troughs are close enough to 0 lags that synchrony is equally plausible.[39] In growth estimates with the dating scheme lagged by −5 years, the alternating pattern of ups and downs is as strong as in the unlagged case.[40]

By combining the two wage series, and thanks to the length of the 1736–1954 series, there are six pairs, barely enough for a t-test (table 10.13). But in the unlagged case, t is significant at the .05 level. With the lag of −5 years, the t-test results are not quite as good.[41] Therefore I tentatively accept that real wages move synchronously (and inversely) with prices and do not lead prices.

These results corroborate long waves in real wages:

Long waves exist in wages. [A]
(Kondratieff)

Long waves do not exist in wages. [R]
(Oparin)

If a decrease in real wages sparks an increase in "class struggle" (strikes, labor insurgencies, etc.), these findings would be consistent with the hypothesis that class struggle peaks late in the upswing:[42]

39. And theoretically preferable, given the effect of prices on real wages.
40. Perfect except one truncated six-year "end" period.
41. The t-test for −5 years is significant at the .05 level for only the U/D pairs, not the D/U pairs.
42. This would be the point in the long wave when real wages were reaching their lowest point, yet production is still high and just beginning to stagnate.

Class struggle peaks during the upswing. [A]
(Kondratieff, Cronin)

Class struggle peaks late in the upswing. [A]
(Mandel, Screpanti)

Class struggle peaks during the downswing. [R]
(Imbert)

Class struggle peaks late in the downswing. [R]
(Gordon)

Summary of Economic Results

In the case of *prices,* there was a strong alternation of estimated growth rates in successive phase periods, unlagged from the base dating scheme. This was strongest in England and in recent centuries (but perhaps just because of better data quality) and weakest in the individual commodity prices in non-core countries. For *production,* long waves were found to lead prices by ten to fifteen years but were weaker than in prices. For *innovation,* long waves were inversely correlated and seemed to lead prices by about five years (lagging production by five to ten years). For *invention,* the results were anomalous—Britain and the United States both seemed to follow the long wave but were out of phase with each other. For *capital investment,* data were inadequate but weakly followed long waves, lagging slightly behind production. For *trade,* no long waves were found. Finally, *real wages* correlated strongly and inversely with the long wave.

The analysis in chapters 9 and 10 has helped sort out the hypotheses concerning

Table 10.13. T-test Results for Two Real Wage Series

Variable	Lag	Pairs[a]	Mean Growth Rate[b] 1st	2d	Diff.	DF[c]	t	Probability[d]
Real Wages	0	Down/Up	.013	-.006	-.019	5	-3.09	.027 *
		Up/Down	-.005	.012	.017	5	2.72	.042 *
Real Wages	-5	Down/Up	.006	-.007	-.013	5	-0.96	.379 –
		Up/Down	-.005	.012	.018	5	3.01	.030 *

Note: Real wage series from 1700 to 1954.

a. Paired phases: D/U = Downswing with following upswing; U/D = upswing with following downswing.

b. 1st = average growth rate for 1st phase in pair; 2d = average growth rate for 2d phase in pair; Diff. = difference in growth rates (2d phase minus 1st). (Differences may show discrepancy due to rounding.)

c. DF = Degrees of freedom = number of phase period pairs minus 1.

d. 2-tailed probability (Either direction of correlation hypothesized).

* indicates statistical significance level below .05.

Table 10.14. Provisionally Accepted Economic Hypotheses

Existence of long waves:
Long waves exist. [A]
(Most long wave researchers)

Scope – variables:
Long waves exist in prices, production and investment. [A]
(Kondratieff, Mandel, Kuczynski, Gordon, Kleinknecht, Delbeke, Van Duijn, Forrester)

Innovations cluster at one point on the long wave. [A]
(Kondratieff, Mensch, Freeman, Forrester, Mandel, Gordon)

Long waves do not exist in trade. [A]
(Oparin, Van der Zwan, Van Ewijk)

Long waves exist in wages. [A]
(Kondratieff)

Scope – temporal:
Long waves at least in prices exist before 1790. [A]
(Imbert, Braudel, Wallerstein)

Historical dating of phases:
The dating of phases is captured in base dating scheme. [A]
Base dating is for prices and 1980 is most recent peak.
(Goldstein, modified)

1940-1980 was a price upswing; 1980- a downswing.
1933-1968 was a production upswing; 1968- a downswing.
(Modified hypotheses resulting from analysis) [A]

Correlations – production:
Production increases precede price increases. [A]
(Imbert)

Correlations – capital investment:
Capital investment increases early in the upswing. [A]
(Kondratieff, Mandel, Gordon, Forrester)

Capital investment is low during the downswing. [A]
(Van Duijn)

Correlations – innovation:
Innovations cluster late in the downswing. [A]
(Gordon, Schumpeter)

Innovations are fewer late in the upswing. [A]
(Forrester)

Correlations – class struggle:
Class struggle peaks late in the upswing. [A]
(Mandel, Screpanti)

economic variables in the long wave. Which hypotheses have been provisionally accepted, and which provisionally rejected, as a result of the economic analysis?

The surviving, provisionally accepted hypotheses concerning the scope and timing of the long wave are listed in table 10.14. The empirical analysis was not able to address the hypotheses concerning "other economic variables" (such as employment, mergers, and currency). But regarding the existence and timing of long waves in the main economic variables, the analysis succeeded in sorting out the contradictory hypotheses into a single consistent scheme. Long waves are tentatively corroborated in prices, production, investment, innovation, and wages (the last two are inversely correlated) but not in trade. They extend from 1495 (at least for prices) through the present. The variables are lagged within cycle time in the following sequence: production, investment, innovation, prices, and wages.

These results corroborate the central hypotheses of each theoretical school. The results support Kondratieff and Forrester on capital investment, Schumpeter on innovation, and Mandel on class struggle and production.

To a large extent the directions of the research presented here have been driven by data. Where few data were available, I pursued what was available. Where only one school of the debate cared to collect data for a certain variable, that school's data were used. As a final comment on the economic time series, I note the relationship between data sources and the results emerging from those data.

The strongest results are found in the class of variables with the highest quality data—prices—and the results become progressively weaker as the data do, moving through production, innovation, and investment. Data sets developed by researchers in one theoretical school tend to support the theory of that school, even though I apply my own methods to the analysis of the data. Kondratieff's price series corroborated his long wave datings. Kuczynski's world production data corroborate his theory of long waves in production. Kleinknecht's innovation data corroborate his distinction between "product" and "improvement" innovations. Thus each school's data tend to support its own theory. While I have sorted out many conflicting hypotheses, the central hypotheses of all three long wave schools remain and are potentially compatible within a single framework. Before that framework can be built, however, the last major long wave variable—war—must be analyzed.