WORKING PAPER

ARE THERE SCHUMPETERIAN WAVES OF INNOVATIONS?

Alfred Kleinknecht
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A-2361 Laxenburg, Austria

FOREWORD

This paper was written in part while the author was a visiting scholar at IIASA. It was written as a contribution to the IIASA-CRPEE Workshop "Life Cycles and Long Waves" held July 7-10, 1987 at Montpellier, France. It is being made available as an IIASA Working Paper because of its relevance to the TES Program.

Robert U. Ayres
Project Leader
Computer Integrated Manufacturing

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by

Alfred Kleinknecht

Rijksuniversiteit Limburg at Maastricht, The Netherlands.

mailing address:
Faculty of Economics RL,
P.O. Box 616,
NL-6200 MD Maastricht.

Abstract:

This paper responds to a recent criticism of the empirical evidence of bunching of innovations. An examination of various long-run innovation samples shows that there is indeed very poor evidence of innovation waves in the time before the mid-19th century. Thereafter, however, two long waves of major innovations occur, both having a lead of approximately 10-15 years over the economic long wave as identified in an earlier study. A t-test confirms that these waves can be clearly distinguished from random fluctuations. In the final section some suggestions for further research are outlined.

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"... there is one hypothesis, now out of fashion, that I would like to back. That is Schumpeter's theory of bouts of investment induced by major technical discoveries. While the new methods are being installed, there is brisk investment and general prosperity, but, after a time, an overshoot is bound to occur, so that excess capacity emerges and brings investment down. I should be prepared to bet that, when the detailed history of the twenty-five years after 1945 comes to be written, it will be seen to have had the character of a boom ... while now there is a formidable overexpansion ..." (Joan Robinson, 1979, p. 46).

0. Introduction: Schumpeter versus Kuznets

In his 1939 Business Cycles, Schumpeter argued that the long-run development of industrial capitalism is characterized by waves of accelerated and decelerated economic growth of some 50 years each. Schumpeter distinguished three such waves:

- first wave: "Industrial Revolution Kondratieff" with an upswing from 1787 to 1814 and a downswing from 1814 to 1842;
- second wave: "Bourgeois (or Railway) Kondratieff" with an upswing from 1843 to 1869 and a downswing from 1870 to 1897;
- third wave: "Neo-mercantilist Kondratieff" with an upswing from 1898 to 1924 and a downswing from 1925 onwards.

A bold extrapolation of the above scheme would lead us to consider the period between the two World Wars as well as the 1970s and 1980s as downswings of the third and fourth Kondratieff waves, while the 1940s up to the early 1970s would be regarded as the upswing phase of the fourth Kondratieff. A renewed upswing of the world economy would then have to be expected somewhere in the 1990s.

According to Schumpeter (1939), each of the above-named upswings can be linked to the emergence and rapid growth of new industrial activities, which were initiated by radical innovations. The subsequent downswings are due to the exhaustion of innovative growth impulses. In order to produce fluctuations which are visible in *macro*-economic data, radical innovations should not be randomly distributed over time but should come about in clusters or waves.

In his famous review of Schumpeter's *Business Cycles* Kuznets spoke of a "host of crucial questions and disturbing doubts" (Kuznets, 1940, p. 262). His criticism referred to three topics in particular: firstly, Schumpeter had failed to give evidence that long waves are not only a price phenomenon, but also exist in "real" indicators of general economic activity (see ibid, p. 267); secondly, Schumpeter's explanation of the alleged long waves implied some bunching of radical innovations which still remained to be empirically proven (see ibid, p. 263); thirdly, Schumpeter had also failed to give a convincing explanation of *why* such a bunching should occur (see ibid, p. 262ff.).

In retrospect, it seems fair to admit that Kuznets has been essentially right on all three points of critique. As theorizing on long waves more or less stagnated during the 1950s and 1960s, the critical questions raised by Kuznets have remained unanswered. On the other hand, Schumpeter's theoretical propositions, if correct, are likely to have some obvious and far-reaching consequences for our understanding of long-run economic growth.

In this paper I shall give particular attention to the second point of Kuznets' critique: Is there any evidence of a discontinuous occurrence of radical innovations? Kuznets' first point has been addressed elsewhere, leading to the conclusion that in a number of industrial core countries there is indeed evidence of a significant long wave pattern in indicators of general economic activity, at least during the last hundred years (Bieshaar and Kleinknecht 1984; see also the comment by Solomou

1986a and the reply by Bieshaar and Kleinknecht 1986). Moreover, Kuznets' point of how to explain a possible bunching of innovations has been discussed extensively in Kleinknecht (1987). The explanation presented there ("depression-trigger" hypothesis), although still being debated (see e.g. Coombs 1987), is beyond the scope of this paper.

I. The Debate on Basic Innovation Clusters.

In recent years, various attempts have been made to collect long-run historical innovation indicators, and particularly to distinguish a few radical breakthroughs in technology from the large stream of smaller piecemeal changes.

To put it metaphorically: there is a real difference between innovators who introduce improved horse cars and those who abolish horse cars by introducing railways or automobiles. A number of imaginative notions have been introduced in order to describe this difference in more general terms. For example, Dosi (1982) recommends that innovations which establish new "technological paradigms" be distinguished from innovations that occur within existing paradigms. Others speak of "basic innovations" versus "improvement innovations" (e.g. Mensch 1975; Van Duijn 1983; Haustein and Neuwirth 1982), or of "New Technology Systems" (Clark et al. 1983), or "New Technological Webs" (Roobeek 1987), or simply of "Major" or "Radical" innovations.

An early attempt by Mensch (1975) to verify the hypothesis that "basic innovations" occur in clusters has been received with scepticism (see e.g. Scholz 1976, Mansfield 1983). In their detailed criticism, Clark et al. (1981) pointed to serious problems in Mensch's data base. They refer to topics such as the representativeness of his data source, his selection procedure, and the determination of innovation years (see ibid, p. 148f).

Their critique has triggered more intense research efforts on long-run innovation patterns which I have treated elsewhere more extensively (Kleinknecht 1987). The results of my examination of various independent sources of long-run innovation indicators eventually confirmed that Clark et al. have been right in criticizing the fact that the original Mensch list of "basic innovations" did indeed underestimate the frequency of basic innovations during the "early upswing" phase of the long waves. This implies that the discontinuity in the rate of major innovations does not manifest itself in narrow clusters during the depth of the depressions (1880s, 1930s) as hypothesized by Mensch, but in virtual waves of major innovations. Table 1 gives a comparison between the original Mensch (1979) periodization of innovation clusters and our dating of periods of stronger and weaker growth and innovation activity. The latter is restricted to periods from the 1860s onwards, because of the poor evidence of macro-economic innovation waves in early capitalism which will become obvious further below.

Table 1: Periods of stronger (+++) and weaker (---) performance

economic growth according to Bieshaar & Kleinknecht (1984, 1986):	1873---1893+++1913---1939+++1974---...
innovation performance (12-years lead) according to Kleinknecht (1987):	1861---1881+++1901---1927+++1962---...
innovation clusters according to Mensch (1979, p. 132):	1815+++1827---1871+++1885---1926; 1926+++1938---1984+++1994.

In view of the evidence derived from various data sets (including their own data), Clark et al. have meanwhile admitted that there might indeed exist a bunching of innovations in certain periods. However, they advocate a different causal explanation (see Clark et al. 1983, p. 74f.)(1)

Following that line, emphasis now seems to shift towards how to explain the observed bunching of innovations (see e.g. the comment by Coombs 1987). Apart from that development, however, there has recently been a contribution by Solomou (1986) which again radically questions the empirical evidence. The next section will be dedicated to that critique.

II. The Solomou critique.

Solomou (1986) examined samples of "basic innovations" by Mensch (1979) and Van Duijn (1983) as well as a sample of "important innovations" by Kleinknecht (1981) as derived from Mahdavi (1972). He concluded that these data are compatible with his random walk (or random shock) hypothesis rather than with a long wave perspective. Besides doing some statistical explorations which will be dealt with further below, Solomou makes several critical remarks on the nature of the data. These can be summarized as follows:

1. in assembling data on basic innovations one is adding up cases of different importance; certainly, some cases are more "basic" than others and hence some weigthing procedure would be desirable.
2. the randomness of Mensch's selection procedure may be doubted (see e.g. the critique by Clark et al. 1981, p. 148f.).
3. if the argument about a relationship between market structure and innovation is valid, then market structure changes between the 19th and the 20th century would make any intertemporal comparison of innovation rates a problematic exercise.
4. since the majority of innovation cases had its origin in the USA, world innovation rates should be linked to the alleged Kuznets-cycle pattern in American economic growth.

Before responding in more detail to points 1. and 2. (which appear to be reasonable points of critique), a few remarks need to be made on points 3. and 4.

As to market structure and R&D activity, the classical survey by Kamien and Schwartz concludes that empirical studies (being based on shaky data, of course) give only little support to a positive relationship (1983, p. 104). Moreover, "Investigation of the supposition that large firms have the best innovative talent have disclosed almost the exact opposite. The largest firms appear to be far less efficient innovators than smaller rivals" (ibid.).

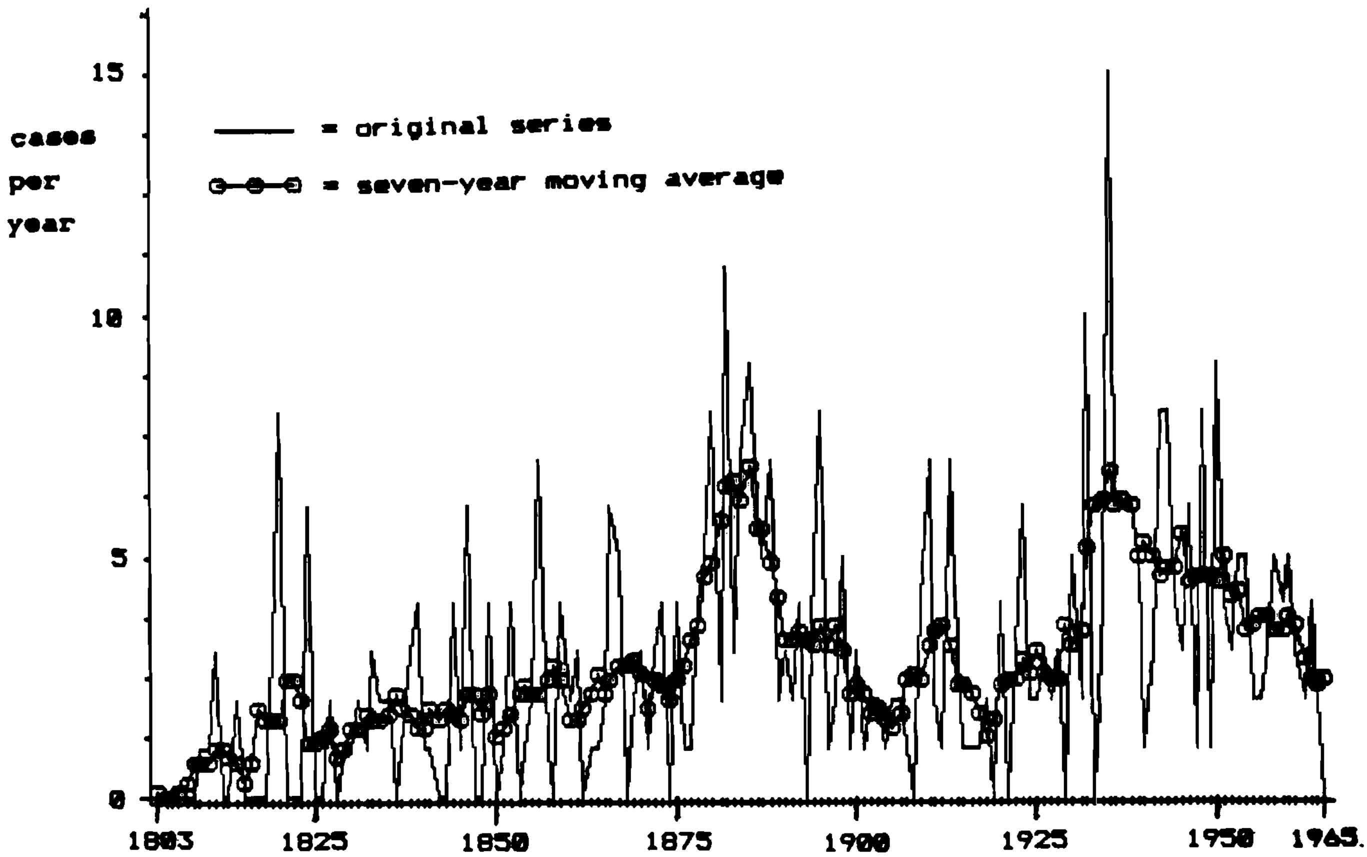
But even if valid, in a long-run historical perspective, changes in market structure would probably have to be conceived as a rather continuous and irreversible process. Consequently, the argument could probably explain a trend increase in innovation rates rather than the type of wave pattern which will show up in our data further below (2) - except if one would argue that market structure changes occur in long waves (this would indeed be a remarkable contribution to the current long wave debate!).

Solomou's argument about linking world innovation rates to the Kuznets cycle pattern in American economic growth (point 4.) is misleading in at least two respects. Firstly, there are reasons to believe that the Kuznets cycle is a statistical artefact, due to problematic filtering effects which result from the use of first differences in detrending economic time series (see Bieshaar and Kleinknecht 1986, p. 190f.). Secondly, provided that the Kuznets cycle exists at all, there seems to be some agreement that it is restricted to the period before World War I (see e.g. the dicussion in Rostow 1975), while US world market hegemony has emerged during the 20th century only and is most obvious after World War II.

While rejecting the above points 3. and 4., the first and second point of critique should be taken seriously. It is a problematic exercise to add up innovations of quite different importance and complexity, and the rate of innovation observed may be biased by the personal whims and preferences of the compiler. For example: a compiler may include cases of "basic" innovations which other compilers would classify as "minor" cases; or, a researcher may use problematic sources and investigate certain historical periods more carefully than other periods. On the other hand, trusting the personal integrity of researchers, one might hope that such biases (although unavoidable) will remain within acceptable limits.

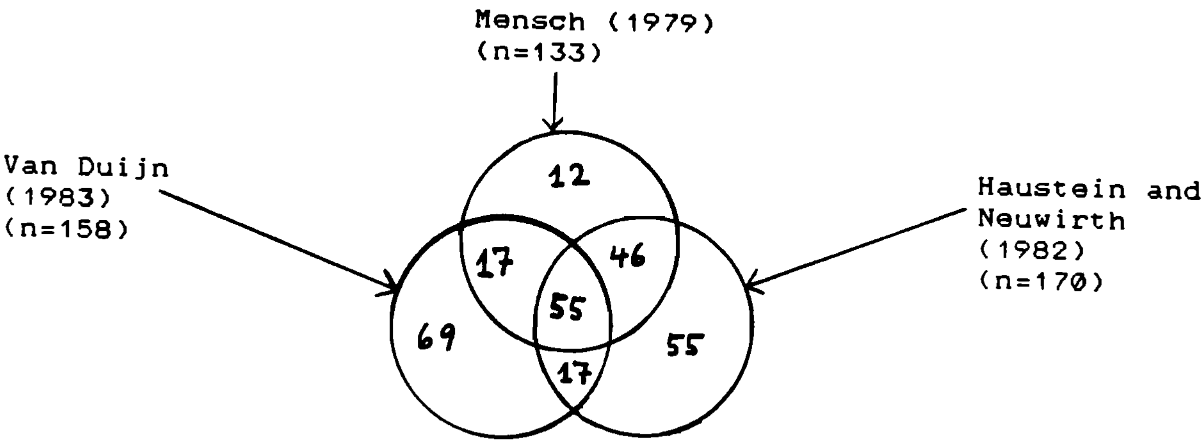
In the following, I shall add up the sets of innovation data by Mensch (1979) (3) and Van Duijn (1983), adding another set of basic innovation data by Haustein and Neuwirth (1982), which has not been considered by Solomou (1986). In doing so, it is hoped that a possible bias from personal judgement by an individual compiler will be reduced. The adding up of all cases from the three samples implies some weighting procedure, since cases which are included in all three samples (and which can therefore most confidently be considered as "basic" innovations, since all three authors agree upon these cases) are counted three times. Cases, which are included in two out of the three sources (which might still be considered as relatively "safe" cases of basic innovations) are counted twice. The category of basic innovations which are reported by one of the three sources only (and which are most likely to cover a number of doubtful cases) are counted only once. Because of the implicit weighting procedure, we would expect the resulting "supersample" to give a more reliable indication of long-run innovation patterns than the isolated consideration of an individual source could do. Only in the extreme case that all three sources had exactly the same bias, our "supersample" would imply no improvement. The "supersample" is displayed in graph 1.

Graph 1: All basic innovations from 3 sources ("supersample") (Annual frequencies from 1803 to 1965).



In order to get an idea about the reliability of the "supersample", it is interesting to see how far the three underlying sources overlap. A schematic presentation of overlaps is given in graph 2. It should be noted that the figures in graph 2 may be subject to some counting errors which are due to the nature of the data: quite frequently, the different sources use a slightly different description of the same innovation case; besides, counting is sometimes complicated because two sources may have considered a different aspect of the same type of innovation (e.g. one source is covering the first commercially successful steamship, while the other source takes the year of the first atlantic crossing of a steamship). Moreover, even for identical events, often diverging innovation years are given

Graph 2: Overlap between 3 samples of basic innovations (1800 - 1968)



(fortunately, most differences in innovation years remain within the range of a few years). In spite of such problems, graph 2 may give at least a rough indication of the overlap between the three sources.

It can be seen in graph 2 that the Mensch (1979) sample shows strong overlap with the other two samples, while the Van Duijn (1983) and the Haustein and Neuwirth (1982) samples have only a modest overlap. This can be explained by the fact that the Mensch sample (being published earlier) has been known to Van Duijn and to Haustein and Neuwirth, while the latter two have been compiling their samples independently of each other. It is remarkable to see that a number of the Mensch cases have not been included in the samples of the other two compilers, which indicates that they must have examined the Mensch sample quite critically.

It should be noted that when forming the "supersample", I deliberately did not interfere with the data, which means that no case was added or omitted; even in the case of diverging innovation years, no innovation year was changed. Besides the above-described supersample, other exercises were done which are not documented here. For example, when adding up all cases from the three sources and omitting those cases which are named in one source only, a pattern similar to that in graph 1 was obtained. The same holds when adding up the Van Duijn and the Haustein and Neuwirth cases, leaving out the Mensch cases.

While the "supersample" certainly is an improvement as compared with the individual sources, it should be noted that the wave pattern in the time distribution of basic innovations does not depend on weighting. This will become clear from our test on the significance of differences in mean innovation rates for various a priori periods, which brings us to another point of the Solomou critique.

Solomou is right in arguing that for testing of the significance of long run innovation patterns, a test on differences in means between certain a priori periods is more appropriate than the runs test as applied by Mensch (1979). It is also correct, that the cyclicity of innovation waves (i.e. their endogenously caused regular recurrence) cannot be proven by any quantitative test, simply because of the low number of waves observed (any proof of cyclicity being left to a theoretically convincing endogenous explanation of the turning points). As Solomou rightly points out, however, one can test a "weak" Kondratieff hypothesis, testing whether observable innovation patterns behave according to what one would expect from a long wave view (ibid, p. 102).

In doing so, I shall apply a one-sided t-test, testing whether the mean number of innovations during the "+++"-periods in Table 1 is significantly higher than during the "---"-periods (and vice versa). The t-test (which is not exactly a student t) is defined as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\delta^2_1}{N_1} + \frac{\delta^2_2}{N_2}}}$$

where: x_1 and x_2 are the sample means
δ^2_1 and δ^2_2 are the sample variances, and
N_1 and N_2 are the sample sizes.

Because of the smaller sample sizes, the use of a t-test for this statistic is more cautious (giving lower levels of significance) than the use of a z-test (as has been done by Solomou, 1986, p. 108). Moreover, since the hypothesized direction of the differences is clearly determined, a one-sided test will be applied. As in Solomou's test it is assumed that the variances during the subsequent "+++"- and "---"-periods are not equal. In the case of the t-test, this assumption implies a considerable loss of degrees of freedom, following the "safe rule" as outlined in Wonnacott and Wonnacott (1977, p. 214).

Table 2 documents the results from application of the t-test to the "supersample". When interpreting table 2, it should be noted that the main difference between my results and those by Solomou (1986) does not seem to be due to the use of a slightly different test formula, but rather to a different periodization.

For example, Solomou applies the Mensch (cluster) periodization (see Table 1 above) to the Van Duijn data. Since the latter show a (broad) wave pattern rather than a narrow cluster pattern, it is not surprising that Solomou finds an almost perfect random walk pattern (see Solomou, 1986, p. 109).

The t-test was also applied to each of the three sources individually, the results being reported in table A1 of the Appendix. Documentation in this paper is restricted to the results which were achieved when handling a 12 years lead of the innovation wave over the economic wave as hypothesized in table 1. In order to test the robustness of the results with regard to slight variations in lead times, a 10 and a 15 years lead was also tried. The results differed only slightly, so that the same conclusions could have been drawn, using a slightly different periodization. Table 2 confirms that the fluctuations observed in figure 1 can clearly be distinguished from statistical random fluctuations.

Table 2: T-test calculations for a priori periods of stronger and weaker innovation performance: the "supersample".

Period:	Means:	SD:	SE:	t-values	d.f.	prob.
1861-1881:	2.6667	2.1525				
			0.8006	1.843	20	0.040
1881-1901:	4.1428	2.9712				
			0.7441	2.481	20	0.011
1901-1927:	2.2962	1.8976				
			0.6291	3.370	26	0.001
1927-1962:	4.4166	3.0740				
			0.7979	2.491	6	0.024
1962-1968:	2.4285	1.6183				

In interpreting table 2, one has of course to be aware, that even if our weighting procedure does imply some improvement, it certainly cannot satisfy all possible objections uttered by sceptics. As has already been indicated above, nobody who has ever been working in the field of innovations research, needs to be reminded of the numerous problems concerning topics such as the representativeness of sources, the randomness of selection principles, the distinction between "major" and "minor" events, an appropriate sample size, or the determination of innovation years.

If, in spite of all these problems, we want to arrive at a somewhat save judgement about Schumpeter's above-sketched hypothesis, we should compare evidence from as many sources as possible. Fortunately, due to the painstaking work by Baker (1976), there is still another long-run technology indicator which has been collected independently of the above basic innovation sources, and which will be considered in the following.

III. Testing the Baker data

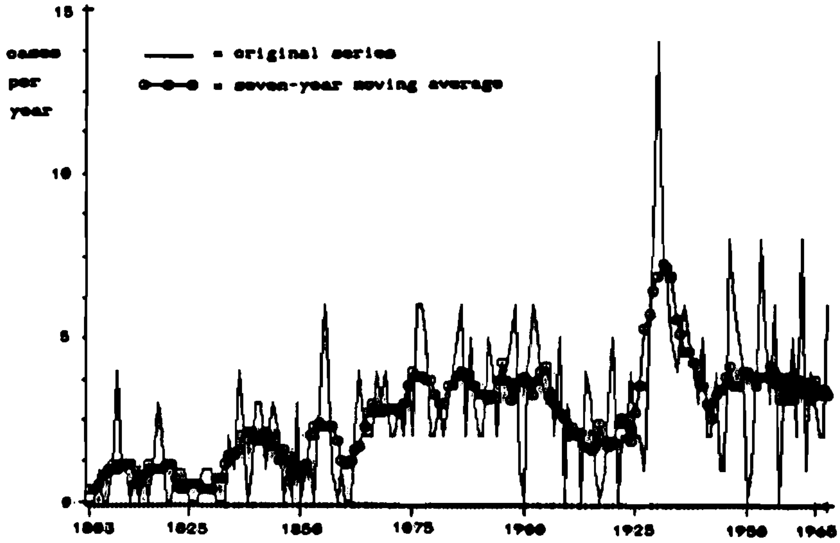
While the above data on "basic innovations" consist of years when the first successful commercialization of new products or processes, perceived to be of fundamental importance, occured, Baker (1976) collected about 1000 "breakthrough" patents which refer to 363 important items (the latter ranging, in alphabetical sequence, from the addressograph up to the zip fastener). It should be mentioned that the basic innovation data are in principle world innovation data, whereas Baker's breakthrough patents are mainly patents registered at the British Patent Office. It can nonetheless be argued that they might be taken as a world innovation indicator, since "The United Kingdom's role in the international world of commerce has been of sufficient importance throughout the history of the patent system to ensure that most inventions of significance would have been subject of patent applications in this country" (Baker 1976, p. 21).

As compared with "direct" innovation data, the Baker patent data have three notable drawbacks. Firstly, the year of publication of a breakthrough patent on a new item is not necessarily identical with the year of the innovation (i.e. the first successful commercialization of the item), although it should come reasonably close to it. Secondly, the Baker sample covers a certain number of key patents which are related to radical inventions rather than innovations. Thirdly, a few cases are related to improvement rather than to "basic" innovations (see also the discussion in Kleinknecht 1987).

These points are likely to constitute a bias in favour of a random walk pattern. Consequently, we would expect fluctuations, as hypothesized in Table 1, to be less accentuated in the Baker data than in "pure" innovation data. A comparison between the

Baker data in graph 3 and the "supersample" of basic innovations in graph 1 seems to confirm this (4). Nonetheless, the results

Graph 3: Product-related breakthrough patents from Baker (1976), according to classification in Kleinknecht (1987).



from application of the above-defined t-test to the Baker data, being documented in Table 3, confirms that the hypothesized fluctuations are still significant, even though significance levels are generally a bit lower than in Table 2.

From Tables 2 and 3, as well as from the test on the individual sources in Table A1 (appendix), it can be concluded that between 1881 and 1962 there is evidence of three successive periods of higher and lower average rates of innovations, the differences being distinguished from random variations at high

Table 3: T-test calculations for a priori periods of stronger and weaker innovation performance: the Baker data.

Period:	mean:	SD:	SE:	t-value	d.f.	prob.
1861-1881:	2.9523	1.4992				
			0.4832	0.985	20	0.163
1881-1901:	3.4285	1.6300				
			0.4853	1.722	20	0.050
1901-1927:	2.5925	1.7155				
			0.5761	3.262	26	0.002
1927-1962:	4.4722	2.8333				
			0.8331	1.046	9	0.157
1962-1971:	3.6000	2.1705				

levels of significance. Judging from the (somewhat more reliable) "supersample" in Table 2, this holds even for the period from 1861 to 1968.

As to the very last period (1962-68), it is of course right that it is often only in retrospect with a certain time-lag that one can decide what are "major" innovations or "minor" ones. Hence, the result from Table 2 can be taken only as a very preliminary indication of a decline of innovation rates during the 1960s. Nonetheless, judging from conventional wisdom, it does not seem to be too bold a prognosis that the 1960s and 1970s will eventually turn out to have been a period of poor innovation performance, followed by a renewed upsurge of radical innovations in the 1980s and 1990s. This would also be a logical implication of my theoretical explanation of innovation waves which is beyond the scope of this paper (see Kleinknecht 1987 for an extensive discussion).

Although a theoretical explanation is important for the issue of _cyclicity_ of the observed waves, this paper is restricted to the statistical evidence which has been questionned by Solomou (1986). Summarizing the above considerations, we can say that Solomou, being right in his critique of Mensch's cluster hypothesis (and its statistical support), draws the wrong conclusions. Innovation flows have _not_ been constant. Besides a 20th century wave of radical innovations, there is evidence of a period of accelerated innovation activity in the 1880s and 1890s, followed by a deceleration up to the late 1920s, which Solomou will not be able to explain by whatever exogenous shock event.

Solomou's random walk hypothesis may hold, however, for the period of early capitalism. Optical inspection of the various time series suggests that, up to the mid-19th century, the flow of innovations in _aggregate_ data experienced only a monotonous increase. This suggests that Schumpeter's innovation-long wave hypothesis as a macro-economic phenomenon (5) is valid only for developed capitalism.

VI. Suggestions for further research

This paper was restricted to empirical evidence of long waves in the incidence of major innovations, which is of course closely related to the issue of long waves in economic life. The explanation of innovation waves which has been put forward in Kleinknecht (1986, 1987) has been discussed controversially. "Alternative" explanations, however, which stress the importance of "science push" and "institutional change" (Clark et al. 1983, Coombs 1987), or which focus on the "social structure of accumulation" (Gordon et al. 1982) are not necessarily inconsistent with my argument that a restructuring of the technological base of capital accumulation is triggered by a prolonged depression. An explanation which integrates the various views would, however, be a task for another paper.

To link innovation waves to long-run profit rates would be another interesting issue. The idea of long waves in aggregate profit rates has recently been advocated by several theorists, e.g. Boccara (1983), Fontvieille (1985), Menshikov and Klimenko (1985), Poletayev (1985), or Reati (1986). In a disaggregated analysis of West German manufacturing profit rates from 1950 to 1977, I have argued that sectors which can be closely related to the 20th century wave of major innovations did have a counteracting influence on a rapid fall of the aggregate profit rate during the 1950s, and in part during the 1960s (Kleinknecht 1987a). Should such an analysis be done for other countries and periods (and, if possible, at a finer level of aggregation), a new light might be shed on the discussion of the Marxian "law" of the falling tendency of the profit rate.

Interpreting the innovation waves from the viewpoint of demand theory may be another research topic, which is likely to be particularly attractive to Keynesian economists. In explaining why innovation waves may cause waves of expansion and contraction in the economy, one would have to consider that launching an innovation involves considerable investment in R&D, know how and eventually the build-up of production facilities; the powerful multiplier effects which result from such investments may be conceived as a positive function of the degree of radicalness of an innovation, the number and impact of subsequent (major and/or minor) innovations, and the degree of market success (diffusion).

Of course, the boom created by such innovation multipliers (which may end in an overshooting such as described in the above quotation by Joan Robinson) still needs to be adequately modelled.

The relationship between demand and innovation still has another implication. To the extend that the "demand-pull" hypothesis (which is not necessarily inconsistent with my "depression-trigger" hypothesis) is valid in explaining innovation, it has an impact on government demand management which has been largely neglected even by Keynesian economists. Government demand, besides having the multiplier effects which are well-known from the textbooks, may influence the flow of innovations (and in doing so create extra demand by means of the above-mentioned "innovation multiplier"). Of course, from a Schumpeterian viewpoint, one would not advocate macro-economic demand impulses. The latter may be (in part) even counter-productive in that they (also) contribute to preserve existing product lines. Rather one would advocate specific demand impulses which are directed towards assisting the emergence of new industrial activities; i.e. government demand may systematically increase the chances of new technological options to survive in the process of Darwinian selection on the market place. Such a demand policy would have the advantage of not only increasing effective demand as such, but also of allowing to make political choices concerning socially desirable new technologies.

The above-sketched arguments may indicate that the hypothesis of innovation waves, if correct, calls for a lot of research work still to be done.

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Notes:

(1) Discussing innovation data on the 20th century chemical industry, they conclude: "All of this supports the notion of bunches of basic inventions and innovations leading to the take-off of new industries, ... It does not, however, demonstrate any direct connection between this process and the 'trigger' of depression" (Clark et al. 1983, p. 74f.).

(2) A similar argument is likely to apply with respect to other long-run structural changes, such as e.g. the rise of the professional R&D lab during the 20th century.

(3) For the 20th century I took the Mensch data as revised by Clark et al. (1983, p. 68f).

(4) It should be mentioned that the Baker data in graph 3 and table 3 refer to product-related breakthrough patents. The process-related patents show a different pattern. A detailed discussion and documentation of the classification of the Baker cases by product versus process patents can be found in Kleinknecht (1987, ch. 4).

(5) Recent work at the International Institute for Applied Systems Analysis at Laxenburg suggests that the diffusion paths of specific technologies (e.g. in the energy and transportation sector or in the steel industry) seem to fit into the framework of Kondratieff long waves, even during those periods in the 18th and 19th century for which evidence of macro-economic long waves appears to be poor; see e.g. Marchetti (1986), Nakicenovic (1986), or Grübler and Nakicenovic (1987).

APPENDIX

Table A1: T-test calculations for upswings and downswings of long waves.

a) Basic innovations according to Van Duijn (1983)

Periods:	mean:	SD:	SE:	t-value	d.f.	prob.
1861-1881:	0.8571	0.7928				
			0.3278	0.871	20	0.192
1881-1901:	1.1428	1.2761				
			0.3137	2.225	20	0.019
1901-1927:	0.4444	0.7510				
			0.2428	2.287	26	0.015
1927-1962:	1.0000	1.1710				
			0.2478	2.824	9	0.015
1962-1971:	0.3000	0.4830				

b) Basic innovations according to Haustein and Neuwirth (1982)

Periods:	mean:	SD:	SE:	t-value	d.f.	prob.
1861-1881:	0.8571	0.9102				
			0.4208	2.149	20	0.022
1881-1901:	1.7619	1.7001				
			0.4042	2.343	20	0.015
1901-1927:	0.8148	0.8337				
			0.2873	2.191	26	0.015
1927-1962:	1.4444	1.3404				
			0.4008	0.428	10	insignif.
1962-1972:	1.2727	1.1037				

c) Mensch's 20th century basic innovations as revised by Clark et al. (1983)

Periods:	mean:	SD:	SE:	t-value	d.f.	prob.
1901-1927:	0.4814	0.8024				
			0.2411	3.302	26	0.001
1927-1962:	1.2777	1.1112				
			0.3507	2.013	6	0.045
1962-1968:	0.5714	0.7867				