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Working Paper

Growth, growth fluctuations, and the stages of technological advance

Kiel Working Papers, No. 327

Provided in cooperation with:
Institut für Weltwirtschaft (IfW)

Kieler Arbeitspapiere
Kiel Working Papers

Kiel Working Paper No. 327

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May 1988

Institut für Weltwirtschaft an der Universität Kiel

The Kiel Institute of World Economics

ISSN 0342-0787

Institut für Weltwirtschaft
Düsternbrooker Weg 120
2300 Kiel
Federal Republic of Germany

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Contents

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1. THE ISSUE

1. It is a well-established tradition to define the subject before embarking on an investigation. In our case, definition is to be concerned with "economic development" and "scientific-technical progress". The former poses no problem in the economist's profession. According to Mirabeau, every moral or physical advance can be grasped by one indicator, which he called the net product. Today, Mirabeau would probably encounter objections as far as the measurement of moral progress by the net product is concerned, although some would argue that also today morals, as well as gods, are always with the winners. Anyhow, real changes in the availability of goods and services is, according to national and international standards, measured by changes in real net social product; conceptual problems - e.g., of how to treat the non-pecuniary costs (environmental pollution) and benefits (value added of housewives) - are, of course, part of every measurement. What matters here is that the approach as such is hardly controversial[1].

2. The definition of scientific-technical progress cannot build upon such a widely-accepted standard. Four stages in the process

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* Revised version of a paper presented at the conference "On Regularities of Scientific-Technical Progress and Long-Term Tendencies of Economic Development" in Novosibirsk, USSR, March 14-18, 1988. - The authors would like to thank their colleagues Christine Kiesner and Fiona Short for their helpful suggestions.

[1] An interesting example of inherent measurement critiques is the Burenstam-Linder (1970) hypothesis of the "hurried-leisure-class".

between creation and application of knowledge may be distinguished:

- Realisation pertains to the new idea ("Erkenntnis"). In many a case, scientific progress stops at this early stage; in non-natural sciences, such as philosophy or the social sciences, realisation is the very essence of progress.
- Making the first use of a new idea is called invention. Such an application of a realisation in the real world is usually correlated with new possibilities of producing or distributing goods or services.
- At the third stage, we have to do with commercial applications of inventions which is called innovation. Again, innovations concern new goods or new modes of production and of distribution of goods and services.
- Finally, of the many innovations only few are economically successful. These successful innovations change the techniques applied throughout the economy, either by new means of production and distribution, or by the availability of new goods or services. These changes in the macro-economic production function are termed technical progress.

This classification distinctly demonstrates that the respective following stage in each case is the concretisation of the preceding stage. In addition, the rôle of profits as a determinant of the activities in each stage becomes more and more important. In other words, at times when, or in countries where, economic incentives are distorted in such a way as to suppress profits, it can be expected that technical progress will suffer the most, scientific realisation the least.

3. The (inter-)relationship between scientific-technical progress and economic development consequently depends on the stage considered. In macro-economic growth analysis, the fourth stage has played the major rôle in quantitative research. In fact, it has been argued that technical progress is the only source of economic growth[2]. This would be a simple truism if all other determinants of growth were to be treated as invariable. Among these other determinants, however, may be the most powerful ones, like those which Schumpeter emphasised (social organisation, politics, "human material", "national spirit" - i.e., prevalent attitudes). However, Schumpeter quite obviously was wrong with regard to the growth process, but right with respect to growth cycles and to sub-optimal growth paths. The reason is simple enough: under the assumption of optimal conditions of social organisation, a further improvement by definition is impossible[3]. Economic growth, then, cannot be achieved by a change in the Schumpeterian determinants. The only variable systematically producing growth is therefore technical progress, which, in turn, should be highest under optimal conditions of social organisation (cf. growth path "Social Conditions I" in Graph 1). In the Schumpeter-scenario, technical progress itself is endogenous and can hardly be separated from economic growth itself.

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[2] Not considered here is an increase in inputs which has positive returns to scale. That is to say, unemployment will not be regarded as a growth problem.

[3] The notion that optimal social conditions are static in the sense that no further systematic improvement over time is possible seems to hold cum grano salis only. However, when excluding improvement of social conditions due to technical progress - such as in data processing - the remaining potential for genuine own progress should indeed be very small relative to technical progress.

4. On the other hand, social conditions are seldomly optimal.

a. In cases of sub-optimality, any improvement leads to a steeper growth path (cf. "Social Conditions II" in Graph 1). This is worth considering because it might clarify the issues: the steeper growth path implies that scientific-technical progress as defined above increases in the long run. Secondly, there should be an improvement in the "degrees of utilisation", i.e., of the allocation of resources of society which makes the actual growth rate observed higher than the "optimal" one for some time; society can be regarded as being in a state of enthusiastic expectations (t1-t2 in Graph 1). This, however, has little to do with scientific-technical advance, in the same way as an upswing in the business cycle cannot be equated with growth. While the latter effect is temporary only, there is also a third effect to be considered, namely catching up with more advanced countries. The catching-up effect, of course, is only relevant if there are technologically-leading countries whose scientific-technical status can be imitated (i.e., if at least one country has had a superior social organisation before). Since catching up can be a rather long-lasting process, the positive growth differential between the reformed economy and the "old" superior economy may also be long-lasting. Catching up implies, of course, that we have only to do with individual countries' scientific-technical progress, not with scientific-technical progress of mankind.

b. If social conditions are optimal, they may not stay so, and of course, sub-optimal conditions can deteriorate further. The question, then, is whether this induces the reverse of the process described above. Again, firstly, the growth path becomes flatter (t3-t4 in Graph 1); secondly, the "degree of utilisation" of society's resources declines, making the overall growth rate even lower than in countries where social conditions were previously in a similarly bad shape. This also is a shorter-run phenomenon, founded on what one may call societal disappointment. However, the analogon to the catching-up processes is hard to see in the deterioration scenario. A further falling back in the scientific-technical status down to a level as if good social conditions had never prevailed would need other explanations, resting rather on macropsychological factors.

5. So far, scientific-technical progress has been analysed for a particular country in a given international environment. It has been argued that:

- STP is basically a trend factor of economic growth;
- technical progress is more dependent on profit rates than the underlying ideas, inventions and innovations;
- changes in social conditions (institutional change) can provide long phases of rapid growth, and long phases of depressed growth;
- transition periods have their upper and lower boundaries defined by two statūs of social conditions; the length of transition periods is yet indeterminate;
- the "upper" transition period is marked by social enthusiasm in the short run, and by catching-up processes over the whole period. The "lower" transition period is marked by social conflicts in the short run;
- STP within the individual country changes along with the social products in the transition periods.

Quite obviously, the picture up until now has been too simple, because a typical feature of the international economy has been neglected, namely international competition. Where there is only one country with a significant lead in technology, the incentives to realise STP in this country will probably be more limited than in the case of two or more countries competing at the technological frontier. In Graph 1, the existence of competition among leading countries is represented by an upward shift of the Social-Conditions-I curve. Thereby, the "world technological market structure" co-determines the potential of catching up for backward countries. Since competition among leading countries widens the scope for economic progress for all countries, technical advance is like a public good for less-advanced countries. In other words: growth paths of countries are interdependent[4].

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[4] The international-competition argument must not be mistaken for the catching-up argument. The former is about the slope of the growth path of the "leading country", the latter is concerned with income differentials between leading and lagging countries. In other words, the first partial derivative in the leading-country argument:

$$\dot{y}_i = \dot{y}_i \ (\dot{y}_k), \ k \neq i,$$

is positive, and in the catching-up argument:

$$\dot{y}_j = \dot{y}_j \ \left(\frac{y_{j,to}}{y_{i,to}}\right), \ j \neq i,$$

it is negative.

y = Social product per capita
$\dot{y}$ = Growth rate of the social product per capita
i = leading country
k = other leading countries
j = lagging country.

In addition, changes in the growth path of leading countries directly impinge upon growth paths of lagging countries, without having changes in the social conditions of lagging countries as a precondition. This is like in "Alice in Wonderland", where one has to run faster in order to keep the same position (here in relative terms).

6. Interdependencies seem to be strongest among countries with equivalent social conditions. Basing his research on Maddison (1982), Baumol (1986) found evidence about the existence of convergence clubs: there is a strong inverse correlation between initial productivity levels of countries and their productivity growth thereafter. As a matter of fact, a first-sight cross-section analysis of 72 countries did not yield any results. But, when countries were grouped according to the degree of industrialisation and type of economic system ("market economies - centrally-planned economies"), it turned out that there were two different "convergence clubs", with convergence - which above has been called catching-up - mainly taking place within each club and hardly between the two clubs. These two clubs are developed-market economies (in Graph 2 "Convergence Club I") and centrally-planned economies (in Graph 2 "Convergence Club II), with isoquants in the growth-rate/productivity-level diagram of market economies north-east to the isoquants of centrally-planned economies. Less-developed countries neither showed convergence among themselves nor with the other two clubs; this is indicated by the cloud of dots labelled LDC in Graph 2. The fact that a small number of LDCs, the newly-industrialising countries, have been joining the industrialised world is also shown in Graph 2. The two convergence paths are empirical results. Assuming that social conditions have not been the same over the whole period to - tn one may draw parallel lines for alternative scenarios, referring to superior (STPI; STPII) or less-advantageous (STPI'; STPII') social conditions.

7. So far, cyclical patterns of scientific-technical progress and of social product have been considered to be endogenous to social conditions. An extension would be the well-known exogenisation of STP cycles: the extension says that ideas, inventions, innovations, and STP occur in clusters over time (Schumpeter, 1939; Freeman, 1983; Mensch, 1975; van Duijn, 1977; Kleinknecht, 1987) and that these discontinuities are, so to speak, part of the natural way technological change evolves. Quite evidently, this view would preclude profit rates as the prime mover of STP. On the contrary, profit rates would instead be endogenous to STP clusters.

8. When analysing fluctuations of STP, or lasting growth differentials among countries, a fundamental question seems to be at hand: how can fluctuations or growth differentials be sustained when intelligence and imagination are evenly distributed among men, nations, or continents, as well as over time? The answer to the latter, the time aspect, may be that societies are incapable of learning from failures and successes of past generations. In other words: societies have a bad memory of all things for social relationships; Schumpeter's notion that economic policies in our time are not shaped by superior wisdom when compared with the policies of Carolus Magnus refers to just this line of thought.

A more general explanation would be that "something" is prior to intelligence and imagination which at times, or places, gives rein to ratio and imagination and at other times, or in other places, encourages both. In concordance with growth analysts in the tradition set by Max Weber (1904), McClelland (1961) and Giersch (1977) stressed the importance of Calvinist ethics for the superior economic growth performance of some highly-industrialised countries. One may call this "something" morals, ethics, or religion.

9. A first objection to such analysis is, of course, that it is hard to test, although historical experience such as scientific, cultural, or economic developments in the wake of 1917 (USSR), 1789 (France), 1688 (United Kingdom), 1949 (Germany), the Meji restoration of 1861 (Japan), the Tai-ping insurrection in the 1860s (China), and so on, in part seems to corroborate this. From the standpoint of critical rationalism, however, explanation of past events is not sufficient unless predictability of future events (instead of ex-post forecasts) is principally possible. In the cases mentioned, this would have been impossible. The reason for this is that radical changes in "religion" and ensuing changes in policies and institutions depend, technically speaking, on random events. According to Hesse (1982), the "normal" case in economic history is the static society; it is the growing society which deserves to be investigated (with a fall to a zero-growth society thus being a return to normality). What has to be carefully looked at, of course, is the "post hoc ergo propter hoc" fallacy, i.e., mistaking coincidence for causality.

10. Below, we shall present a description of the method by which the causal relationships, if any, between STP and economic development is empirically analysed (section II). Section III is concerned with a description of the data and section IV with an application of the causality test for the UK, the USA, and Germany from the last century to the present.

2. THE METHOD

11. The procedure applied below uses the methodology of causality testing as proposed by Granger (1969), Sims (1972) and Pierce and Haugh (1977), and applied by Clark, Chakrabarti and Chiang (1988). The underlying idea is that a variable X is causal with respect to Y if introduction into an autoregressive equation of Y significantly reduces the variance of errors in forecasting Y. The inclusion of further explanatory variables follows the same reasoning. With S^2_{yx} as the residual variance of Y_t with respect to the information Y_{t-n} and X_{t-m}, one may write (Granger Test):

$$S^2_{yx}\ [Y_t | Y_{t-n},\ X_{t-m}] < S^2_y\ [Y_t | Y_{t-n}]$$

$$\text{with } n,m \geq 1$$

S^2_y is the variance of errors in forecasting Y_t when only Y_{t-n} is given. Whenever S^2_{yx} is significantly smaller than S^2_y, X is causal to Y in the Granger sense.

12. The concept of causality needs qualification. In the philosophical sense of the word, causality implies that two events are logically connected. Granger causality has a softer definition. Firstly, the test is concerned with intertemporal statistical relationships. It thus can necessarily only test causality with respect to the statistics and to the temporal relationships. Causality in social phenomena has intelligent (economic) agents between cause and consequence, i.e., expectations as well as learning, or habits, co-determine the consequences of causes[5]. Second-

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[5] A prominent example has been the observed "causal" relationship between the inflation rate and government bond yields, where it has been shown that - quite contrary to the interpretation of the statistical results - expectations make the bond yields of today dependant on assumed inflation rates of tomorrow (Schwert 1979).

ly, the Granger test is concerned with the marginal contribution of an explanatory variable. This is the reason why it has been suggested to substitute the "five-letter word" cause with "temporally related", "content of incremental predictability" or, more technically, "a reduction in forecasting variance with respect to a given information set" (Zellner 1979). Whenever we use the word "causality" below this will be in the sense of Granger causality.

13. A problem of measurement is the way in which statistical information should enter the Granger test. Granger himself prefiltered his data by subtracting a log-function transformation from a constant term. Others used first differences. Filtering in economic time series analysis is not exactly neutral to the results achieved; furthermore, filtering can substantially reduce the information contained in the original data. However, the use of completely unfiltered data in the case considered here would lead to spurringly high coefficients of determination due to the trends in the data used and would thereby distort the information on the impact of incremental variables (see the formal presentation of the Granger test below). Test runs using only log-transformed data indeed exhibited strong signs of trend correlations.

In the course of calculations it turned out that the most appropriate procedure - i.e. the procedure providing the highest degrees of incremental predictability - would be to take into account the evidence of Kondratieff cycles in long-run economic development. Thus, we first determined the lower turning points in the Kondratieff cycles of the net-social products (NSP) of the countries considered (Source: Glismann, Rodemer, Wolter 1981).

After estimation of the cycle-specific trends of NSP these were subtracted from the real NSP data (all data log-transformed).

14. The direct Granger test will be performed by testing the following regression:

$$\Delta NSP(t) = \sum_{n=1}^{20} a1(n)\Delta NSP(t-n) + \sum_{m=1}^{20} b1(m)\Delta Pat(t-m) + \sum_{k=0}^{20} c1(k)\Delta T(t-k) + e1(t) \qquad (1)$$

with
- Δ: change
- NSP: net social product at constant prices
- Pat: invention indicator (patents granted)
- ΔT: technological gap relative to the leading country
- a1(n), b1(m), c1(k): regression coefficients
- e1(t): disturbance term (without serial correlation).

The null hypothesis is defined as b1(m) = 0 for all m, and c1(k) = 0 for all k, i.e., inventions, or catching up, do not cause ΔNSP. This will be tested by the F statistics. Rejection of the null hypothesis would indicate causality. Note that the possibility of a contemporaneous relationship is only included with respect to the catchingup hypothesis. It is by definition excluded for the autoregressive term, and it does not seem to make sense in the light of the above discussion for the invention hypothesis.

In addition, changes in incomes may cause changes in invention activities, the same holds true for technological gaps. This would require the above test to be performed twice in the reverse direction:

$$\Delta Pat(t) = \sum_{m=1}^{20} b2(m)\Delta Pat(t-m) + \sum_{n=1}^{20} a2(n)\Delta NSP(t-n) \qquad (2)$$

$$+ \sum_{k=1}^{20} c2(k)\Delta T(t-k) + e2(t)$$

$$\Delta T(t) = \sum_{k=1}^{20} c3(k)\Delta T(t-k) + \sum_{n=1}^{20} a3(n)\Delta NSP(t-n) \quad (3)$$

$$+ \sum_{m=1}^{20} b3(m)\Delta Pat(t-m) + e3(t)$$

Again, the null hypothesis is that a2(n) =0 for all n and c2(k) = 0 for all k in equation (2); the same holds true for a3(n) and b3(m) in equation (3). Refutation would imply that ΔPat, or ΔT, is caused by the respective variable rejected.

15. In other words:

(I) if b1(m) = 0 and a2(n) = 0 is rejected, then a two-way causality between economic development and invention performance cannot be excluded.

(II) if b1(m) = 0 and a2(n) = 0 is not rejected, then no causal relationship exists.

(III) if b1(m) = 0 is rejected and a2(n) = 0 is not rejected, then a one-way causality running from invention performance to economic development cannot be excluded.

(IV) if b1(m) = 0 is not rejected and a2(n) = 0 is rejected, then a one-way causality going from economic development to invention performance is indicated.

The analogous reasoning applies to the interpretation with respect to the interrelationship between economic development and technological gaps [i.e., c1(k) and a3(n)], and to the interrelationship between invention performance and technology gaps [i.e., c2(k) and b3(m)].

16. In order to assess the significance of the variables incre-

mental to the autoregressive relationship, a restricted version must be compared to a less restricted version of equations (1), (2) and (3). The degree of restriction refers to the number of sets of incremental variables for which the regression coefficients are assumed to be zero. Thus, the full equation (which includes all incremental variables) is called the unrestricted equation. The first-order restricted version is identical with the autoregressive relationship; the second-order restriction includes one of the two incremental variables respectively. Comparison of the resulting residuals is made when computing the F statistics:

$$F = \frac{(SE_{r1} - SE_{r2})/(DF_{r1} - DF_{r2})}{SE_{r2}/DF_{r2}} ,$$

where SE_{r1} is the squared error of the first-order restriction estimate, and SE_{r2} is the squared error of the second-order restriction estimate; DF refers to the respective degrees of freedom. Comparison of the "full" equation - in the above terminology the unrestricted equation - with the two second-order equations is calculated analogously. Finally, comparison between the autoregressive equation and the unrestricted equation (with the two sets of incremental variables) is to indicate the quality of the incremental variables combined.

17. A general most pertinent problem is that of the degrees of freedom left when lead and lag structures are fully exploited. In case such a problem occurs, a step-by-step precedure has to be employed - alternatively setting e.g., b1 or c1, a2 or c2, and a3 or c3 equal to zero. The most appropiate lag structure was pretested in bivariate analysis.

3. THE DATA

18. The data used in the regressions presented here are transformed by passing the filtering process as described in para 13. As the formulation of regressions (1) to (3) indicates, the maximum lag is assumed to be 20 years, or roughly almost half a Kondratieff cycle. Lags of 20 years should be the maximum applicable to the Kondratieff cycle because - if any cyclical regularity exists at all - any additional lag would imply the probability of spurious relationships in the form of echoing.

19. According to the four-stages scenario described above, measurement of the interrelationship between economic development and scientific-technical progress should take each single stage into consideration. This is not possible, because there are no statistics on "realisation". As regards invention, patent statistics of the three countries analysed below are the best information available. Two aspects pertinent to the patent variable seem to be important: firstly, the choice to use patents granted rather than patent applications is necessarily arbitrary. Grants are applications which have passed a screening process for technical novelty. They give, so to speak, information on really "incremental" technical change. Secondly, they may not be as responsive to long-run cyclical patterns as patent applications are (which is an advantage rather than a disadvantage).

20. Innovation data have some well-known and widely-discussed drawbacks, among which are the filters in individual perception

of the relevance of an innovation (in case "major innovations" are counted), the limited knowledge of accountants, the practical impossibility of economic ranking of innovations, and, not least, the dating of an innovation.

Below we construct an index of "major innovations" by computing an unweighted average of experts' opinions. The experts are mainly Haustein/Neuwirth, Kleinknecht, Mensch, van Duijn, and the many sources quoted therein, as compiled by Kleinknecht (1987). Of course, one drawback which can be considered additional to the ones listed above is that all these experts are simultaneously experts on long waves of economic development, which could introduce one or another spurious correlation; but, of course, this possibility is only very faint.

21. The other variables used in the regressions are, generally speaking, "social products" per capita at constant market prices, and the relative real "social products" per capita as a proxy for the catching-up potential. The net social product is available for Germany, the gross domestic product for the United Kingdom; and the gross social product for the United States . The differences thus occur mainly with respect to the inclusion or exclusion of depreciations and of net factor incomes from abroad. Since the problem of data availability in long-term analyses is by far greater than the problem of strictly identical definitions, and since the emphasis is on the analysis of each country's own economic development, this should not matter too much. There could, however, be a bias in the overlapping term of technology gaps (which are measured as relative per-capita incomes).

In order to avoid such discrepencies, the proxies for the technology gap have been taken from Maddison (1987) who supplies standardised income figures for these countries, denominated at constant purchasing power parities[7].

4. THE RESULTS

22. The evidence in Tables 1, 2 and 3 is pertinent to the Granger tests presented in Table 4. It should be noted that the Granger test means comparing (two) equations (cf. para 16). Tables 1 to 3 provide the inputs necessary for such a comparison. Since the autoregressive as well as the incremental variables enter the equations as a combination of four lags each, an interpretative caveat is in place. The lag combination for each variable makes the possibility of multicollinearity within each set of lags inevitable. Thus, coefficients, significance levels and eventually signs can be supposed to be distorted by this multicollinearity. Therefore, it seems to make little sense to argue about specific regression co-efficients in Tables 1 to 3. Some patterns, however, stand out with respect to the countries and the stages of technological advance:

- Invention activities as measured by patents granted over time have had no discernible effect in Germany, whereas it played a major, though different rôle in the other two countries. In the

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[7] This raises the question as to why the Maddison data have not been applied for the NSP variables. The reason is that any transformation by exchange rates, or purchasing power parities, has intrinsic empirical problems which tend to reduce the quality of the data. In the case of the T variable such a transformation is, however, inevitable.

United States a long-run one way impact of inventions on the national product prevailed; in the United Kingdom a similar long-run effect can be observed, but also a short run feedback running in the reverse direction, implying that the better economic performance is, the lower is invention activity.

- Innovations have been important in all cases considered. The evidence for Germany and the United Kingdom would suggest that innovations - here defined as an international variable common for all countries - have primarily enlarged the catching-up potential of economically backward countries. This interpretation is substantiated by the relatively short time lags between innovation and economic activity in the United States: The United States having been the leading country for most of the period considered should have contributed the most to international innovations.
- By and large, the results are compatible with the four-stages scenario discussed above: inventions have the longest lag until the social product reacts (if at all); catching up has the most immediate impact, and innovations are inbetween. A clear case is the United States, where invention activity seems to have affected economic development with a long lag (19 and 20 years); innovations had a much shorter time lag. Ambiguity in sign exists with regard to both variables, and a short-lag reverse relationship running from economic development to innovation is also shown.

23. As is obvious from Table 3 the case of the United States is different from the two European countries in one important aspect: catching up has per definitionem been impossible because

the US has been the "leading country" since the turn of the century. Consequently, only the relationship between inventions and economic development and between innovations and economic development were to be tested.

One should have expected major differences between the United Kingdom and Germany as well, for mainly two reasons. Firstly, the UK has been declining relative to other countries in economic terms since the end of the last century; secondly, besides slow growth, the UK has been far less exposed to the structural and political changes in the 20th century. Indeed, the catching-up variable shows distinct influences on innovations and inventions in the case of the United Kingdom, but not in the case of Germany.

24. The regressions analysed above do not give insight into whether the variables which are incremental to the autoregressive terms lead to a significant incremental reduction of the forecasting error. Table 4 reveals the incremental value of these hypotheses. It shows that a range of relationships can be substantiated.

25. In the case of Germany the results are quite clear and in line with the model developed above: There is a straight causal relationship running from innovations to catching-up and from there to economic growth. The latter again has an impact on inventive activities. Invention activities are also directly dependant on the catching-up variable, which at a first glance comes as a surprise.

The interpretation of these results may be like this:

- The catching-up variable seems to be a proxy both for the first stage of STP, namely realisation, as well as for the last stage, namely "technical progress". Indeed, it appears quite plausible that some of the inventions are built upon leading countries' examples and that, at the same time, these examples directly contribute to economic development.
- The international innovation variable contributed to the reduction of the German technology gap.

When considering that of the sixteen comparisons of equations shown in Table 4 only four are significant, two of them at the 10 % level only, one may also conclude that those theories which try to explain German economic development by institutional changes and the factor-price movements resulting from these changes are indirectly supported.

26. In the case of the United Kingdom, results are different from the German case because (1) catching up did not play any incremental rôle in explaining economic development; instead, (2) innovations with a lag between nine and twelve-years directly affected economic growth. Common with the results for Germany is the impact of economic development on invention activity and also the rôle of catching-up as a proxy for realisation. In addition, economic development correlated, probably through the definitional ties, with the technological gap.

27. In the case of the United States, the results again differ from those for Germany and the UK: patenting has been of major and direct importance for the US economy, with the longest lag identified at all, namely of 19 and 20 years. In addition, innovations affected directly economic development like in the United

Kingdom. The impact of economic growth on inventions is similar to that in the other two countries.

5. CONCLUDING REMARK

28. Basically, the applied Granger test does not solve the problem of causality regarding the interrelationship of STP and economic development. Instead, it reveals incremental reductions of forecasting errors. While the causality issue as such is presumably not solvable by such econometrics, the forecasting quality might be improved by refinements in the procedure. Such refinements pertain most certainly to a more comprehensive analysis of alternative sets of lag structures in the temporaneous relationships among the variables; whether the application of other, maybe less distorting, filters would improve the insight into the macroeconomic relationships is a matter of fact. Our impression is that there are limits set by the data base.

REFERENCES

Abramovitz, Moses (1986). Catching Up and Falling Behind. Economic Research Report No. 1. Trade Union Institute for Economic Research, Stockholm.

Baumol, William J. (1986). Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show. In: American Economic Review, Vol. 76, No. 5, pp. 1073-1085.

Brunner, Karl, and Meltzer, Allan H. (1979). Three Aspects of Policy and Policy Making: Knowledge, Data and Institutions. North Holland Publishing Company, Amsterdam, New York, Oxford.

Burenstam-Linder, Staffan (1970). The Hurried Leisure Class. Columbia University Press, New York and London.

Clark, John, Freeman, Christopher, and Soete, Luc (1983). Long Waves, Inventions, and Innovations. In: Christopher Freeman (ed.), Long Waves in the World Economy. Butterworths, pp. 63-77. London.

Clark, John J., Chakrabarti, Alok K., and Chiang, Thomas C. Stock (1988). Prices and Merger Movements: Interactive Relations. In: Weltwirtschaftliches Archiv (forthcoming).

Giersch, Herbert (1977). Konjunktur- und Wachstumspolitik in der offenen Wirtschaft. Th. Gabler, Wiesbaden.

Glismann, Hans H., Rodemer, Horst, and Wolter, Frank (1981). Lange Wellen wirtschaftlicher Entwicklung (Replik und Weiterführung). In: Dietmar Petzina, Ger van Roon: Konjunktur, Krise, Gesellschaft. Klett-Cotta, Stuttgart.

Granger, C.W.J. (1969). Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. In: Econometrica, Vol. 37, pp. 424-438.

Hesse, Günther (1982). Die Entstehung industrialisierter Volkswirtschaften. Ein Beitrag zur theoretischen und empirischen Analyse der langfristigen wirtschaftlichen Entwicklung. J.C.B. Mohr, Tübingen.

Kleinknecht, Alfred (1987). Innovation Patterns in Crisis and Prosperity. Schumpeter's Long Cycle Reconsidered. Macmillan Press, London, Hong Kong.

Maddison, Angus (1982). Phases of Capitalist Development. Oxford University Press, New York.

Maddison, Angus (June 1987). Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment. In: Journal of Economic Literature, Vol. XXV, pp. 649-698.

McClelland, David C. (1961) The Achieving Society. Van Nostrand, Princeton.

Mensch, Gerhard (1975). Das technologische Patt. Umschau Verlag, Frankfurt.

Pierce, David A., and Haugh, Larry D. (1977). Causality in Temporal Systems: Characterization and a Survey. In: Journal of Econometrics, Vol. 5, pp. 265-293.

Schumpeter, Joseph A. (1939). Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process. McGraw Hill, Vol. 1,2, New York and London.

Schwert, G. William (1979). Tests of Causality. The Message in the Innovations. In: Karl Brunner, Alan H. Meltzer (Eds.). Three Aspects of Policy and Policy making. North Holland Publishing Company, Amsterdam, New York, Oxford.

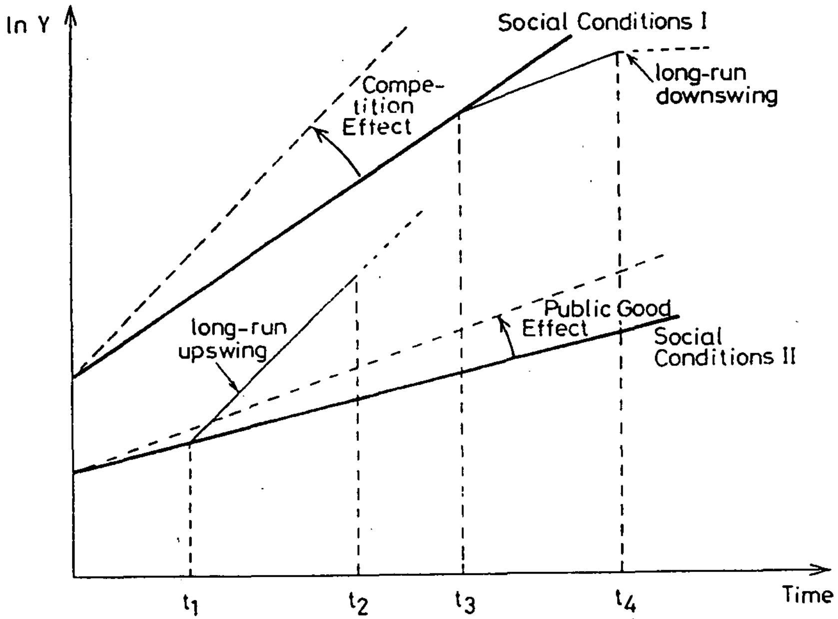
Sims, Christopher A. (1972). Money, Income and Causality. In: American Economic Review, pp.540-552.

Van Duijn, J.J. (1977). The Long Wave in Economic Life. In: De Economist, Vol. 125, pp. 544-576, Leiden.

Weber, Max (1904/05). Die protestantische Ethik und der "Geist" des Kapitalismus. In: Archiv für Sozialwissenschaft und Sozialpolitik, Bd. 20, 1904, pp. 1-54 and Bd. 21, 1905, pp. 1-11.

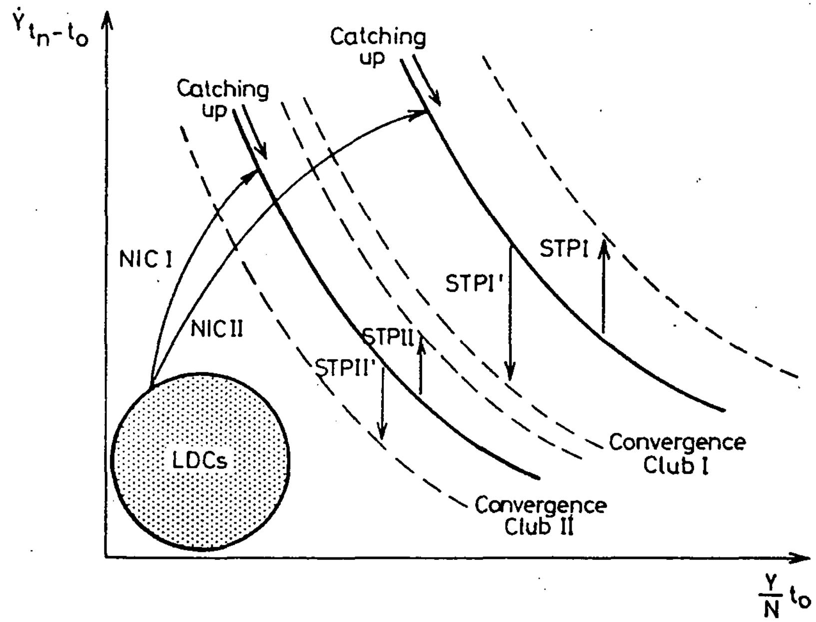
Zellner, Arnold (1979). Causality and Econometrics. In: Karl Brunner, Alan H. Meltzer ... (cf. Schwert, G. William).

Graph 1: Growth, Institutional Change, and Growth Fluctuations



Y	:	Social product
t_1	:	begin of the long-run upswing
t_3	:	begin of the long-run downswing
t_1t_2	:	"enthusiasm"/catching-up
t_2t_3	:	catching-up
t_3t_4	:	"disappointment" plus falling behind
t_4	:	falling behind

Graph 2: Convergence, and Scientific-Technical Progress



$\dot{Y}$	:	Rate of growth of social product
$\frac{Y}{N}$	:	Per capita social product
to	:	begin of period
tn	:	end of period
NIC	:	applicants for convergence clubs I or II ("newly industrialising countries")
STPI (II)	:	Scientific-technical progress in convergence club I (II): upswing
STPI' (II')	:	Scientific-technical progress : downswing

Table 1: Granger Test Estimates on Scientific-Technical Progress and Economic Development: Germany

Equation No.	Dependent Variable	Increm. Variable	Coefficient of Lagged Dep. Variable				Coefficient of First Incremental Variable				Coefficient of Second Variable				$\bar{R}^2$	F	D.W
			a1	a1	a1	a1	b1	b1	b1	b1	c1	c1	c1	c1			
(1) (a)	NSP	Pat, T	0.99	-0.19	-0.06	-0.02	---	---	---	---	---	---	---	---	0.64	37.3	1.99
		t-stat.	(8.64)	(-1.19)	(-0.37)	(-0.17)											
		lag	1	2	3	4											
(1) (b)	NSP	Pat, T	0.99	-0.19	-0.07	-0.01	0.00	0.01	0.01	-0.00	---	---	---	---	0.63	17.8	1.99
		t-stat.	(8.40)	(-1.14)	(-0.41)	(-0.11)	(0.02)	(0.28)	(0.26)	(-0.21)							
		lag	1	2	3	4	6	7	8	9							
(1) (c)	NSP	Pat, T	1.03	-0.24	-0.27	0.20	---	---	---	---	-0.13	0.17	0.38	-0.37	0.67	22.2	2.04
		t-stat.	(6.42)	(-1.00)	(-1.14)	(1.22)					(-0.65)	(0.58)	(1.31)	(-1.87)			
		lag	1	2	3	4					1	2	3	4			
(1) (d)	NSP	Pat, T	1.07	-0.29	-0.30	0.25	0.01	0.01	-0.00	-0.01	-0.18	0.22	0.42	-0.42	0.64	12.9	2.05
		t-stat.	(6.05)	(-1.07)	(-1.10)	(1.34)	(0.29)	(0.42)	(-0.03)	(-0.36)	(-0.82)	(0.66)	(1.28)	(-1.93)			
		lag	1	2	3	4	6	7	8	9	1	2	3	4			
(1.1) (b)	NSP	INN, T	0.89	-0.17	-0.08	-0.05	-0.02	-0.01	0.02	-0.02	---	---	---	---	0.55	11.7	2.06
		t-stat.	(7.07)	(-1.03)	(-0.48)	(-0.43)	(-0.90)	(-0.31)	(0.74)	(-0.78)							
		lag	1	2	3	4	4	5	6	7							
(1.1) (d)	NSP	INN, T	0.78	-0.11	-0.40	0.16	-0.03	-0.01	0.03	-0.01	0.52	-0.19	-0.19	0.05	0.59	9.4	1.96
		t-stat.	(5.99)	(-0.69)	(-1.95)	(0.91)	(-1.22)	(-0.47)	(0.97)	(-0.49)	(2.45)	(-0.72)	(-0.94)	(0.34)			
		lag	1	2	3	4	4	5	6	7	8	9	10	11			
			b2	b2	b2	b2	a2	a2	a2	a2	c2	c2	c2	c2			
(2) (a)	Pat	NSP, T	0.14	-0.10	-0.22	0.03	---	---	---	---	---	---	---	---	0.04	1.8	2.02
		t-stat.	(1.24)	(-0.88)	(-1.96)	(0.27)											
		lag	1	2	3	4											
(2) (b)	Pat	NSP, T	0.27	-0.22	-0.19	0.00	-1.30	0.08	0.14	0.20	---	---	---	---	0.08	1.9	2.02
		t-stat.	(0.23)	(-1.86)	(-1.35)	(0.00)	(-1.69)	(0.07)	(0.14)	(0.34)							
		lag	1	2	3	4	3	4	5	6							
(2) (c)	Pat	NSP, T	0.06	-0.04	-0.41	0.21	---	---	---	---	-1.00	1.69	-2.80	0.90	0.10	2.2	2.07
		t-stat.	(0.57)	(-0.22)	(-2.25)	(1.26)					(-0.87)	(0.92)	(-1.56)	(0.78)			
		lag	1	2	3	4					2	3	4	5			
(2) (d)	Pat	NSP, T	-0.01	-0.13	-0.44	0.11	-1.46	0.76	0.15	0.27	-0.81	2.72	-3.17	0.28	0.11	1.9	2.05
		t-stat.	(-0.10)	(-0.72)	(-2.35)	(0.63)	(-1.63)	(0.58)	(0.13)	(0.45)	(-0.69)	(1.41)	(-1.54)	(0.21)			
		lag	1	2	3	4	3	4	5	6	2	3	4	5			

still Table 1: <u>Germany</u>

Equation No.	Dependent Variable	Increm. Variable	Coefficient of Lagged Dep. Variable				Coefficient of First Incremental Variable				Coefficient of Second Variable				$\bar{R}^2$	F	D.W
			b2	b2	b2	b2	a2	a2	a2	a2	c2	c2	c2	c2			
(2.1) (a)	Inn	NSP, T	0.77	-0.13	-0.08	0.02	---	---	---	---	---	---	---	---	0.43	14.7	2.00
		t-stat.	(6.39)	(-0.84)	(-0.59)	(0.17)											
		lag	1	2	3	4											
(2.1) (b)	Inn	NSP, T	0.75	-0.12	-0.07	-0.01	0.20	-0.61	0.03	-0.24	---	---	---	---	0.42	7.5	2.00
		t-stat.	(5.96)	(-0.74)	(-0.49)	(-0.05)	(0.33)	(-0.74)	(0.04)	(-0.39)							
		lag	1	2	3	4	3	4	5	6							
(2.1) (c)	Inn	NSP, T	0.76	-0.11	-0.10	0.14	---	---	---	---	-0.36	0.12	0.40	-0.53	0.41	7.3	2.00
		t-stat.	(6.21)	(-0.73)	(-0.64)	(0.11)					(-0.48)	(0.11)	(0.39)	(-0.71)			
		lag	1	2	3	4					2	3	4	5			
(2.1) (d)	Inn	NSP, T	0.72	-0.07	-0.05	-0.07	1.14	-2.29	0.70	-0.42	-0.58	-1.24	2.63	-0.92	0.43	14.7	2.00
		t-stat.	(5.56)	(-0.42)	(-0.29)	(-0.58)	(1.18)	(-1.69)	(0.62)	(-0.66)	(-0.72)	(-0.85)	(1.54)	(-0.81)			
		lag	1	2	3	4	3	4	5	6	2	3	4	5			
			c3	c3	c3	c3	a3	a3	a3	a3	b3	b3	b3	b3			
(3) (a)	T	NSP, PAT	0.95	-0.01	0.00	-0.22	---	---	---	---	---	---	---	---	0.74	60.4	2.05
		t-stat.	(8.58)	(-0.10)	(0.02)	(-2.02)											
		lag	1	2	3	4											
(3) (b)	T	NSP, PAT	0.95	-0.01	0.14	-0.25	0.04	-0.04	0.01	0.04	---	---	---	---	0.73	28.9	2.06
		t-stat.	(8.36)	(-0.07)	(0.09)	(-1.88)	(0.36)	(-0.31)	(0.08)	(0.42)							
		lag	1	2	3	4	4	5	6	7							
(3) (c)	T	NSP, PAT	0.93	-0.02	-0.01	-0.21	---	---	---	---	0.01	0.00	0.01	0.01	0.73	24.2	2.06
		t-stat.	(7.52)	(-0.09)	(-0.04)	(-1.66)					(0.40)	(0.21)	(0.80)	(0.55)			
		lag	1	2	3	4					16	17	18	19			
(3) (d)	T	NSP, PAT	0.93	-0.01	0.02	-0.21	0.02	-0.05	0.02	0.03	0.01	0.00	0.01	0.01	0.71	15.2	2.06
		t-stat.	(7.20)	(-0.08)	(0.09)	(-1.38)	(0.17)	(-0.34)	(0.14)	(0.32)	(0.37)	(0.19)	(0.78)	(0.56)			
		lag	1	2	3	4	4	5	6	7	16	17	18	19			
(3.1) (c)	T	NSP, INN	0.95	0.13	-0.18	-0.18	---	---	---	---	0.07	-0.08	-0.00	0.03	0.79	31.2	2.16
		t-stat.	(7.52)	(0.73)	(-1.09)	(-1.53)					(3.57)	(-3.28)	(-0.16)	(1.31)			
		lag	1	2	3	4					9	10	11	12			
(3.1) (d)	T	NSP, INN	0.92	0.10	0.17	-0.43	-0.35	0.35	-0.09	0.01	0.07	-0.08	-0.01	0.02	0.80	22.7	2.09
		t-stat.	(7.20)	(0.55)	(0.83)	(-2.68)	(-2.74)	(2.22)	(-0.68)	(0.13)	(3.85)	(-3.44)	(-0.05)	(1.13)			
		lag	1	2	3	4	3	4	5	6	9	10	11	12			

Notes: The figures in paratheses are t statistics. - D.W denotes Durbin-Watson-statistics.

Source: Own calculations.

Table 2: Granger Test Estimates on Scientific-Technical Progress and Economic Development: United Kingdom

Equation No.	Dependent Variable	Increm. Variable	Coefficient of Lagged Dep. Variable				Coefficient of First Incremental Variable				Coefficient of Second Variable				$\bar{R}^2$	F	D.W
			a1	a1	a1	a1	b1	b1	b1	b1	c1	c1	c1	c1			
(1) (a)	NSP	Pat, T	1.13	-0.22	-0.08	-0.10	---	---	---	---	---	---	---	---	0.79	80.4	1.99
		t-stat.	(10.26)	(-1.32)	(-0.48)	(-0.89)											
			1	2	3	4											
(1) (b)	NSP	Pat, T	1.13	-0.24	-0.06	-0.13	0.06	-0.06	0.02	-0.01	---	---	---	---	0.80	41.9	1.98
		t-stat.	(10.10)	(-1.46)	(-0.39)	(-1.16)	(2.38)	(-1.88)	(0.81)	(-0.45)							
		lag	1	2	3	4	12	13	14	15							
(1) (c)	NSP	Pat, T	1.12	-0.23	-0.09	-0.08	---	---	---	---	-0.33	0.69	-0.40	-0.06	0.79	40.9	1.97
		t-stat.	(9.92)	(-1.35)	(-0.55)	(-0.69)					(-0.97)	(1.50)	(-0.85)	(-0.17)			
		lag	1	2	3	4					9	10	11	12			
(1) (d)	NSP	Pat, T	1.16	-0.29	-0.04	-0.12	-0.05	-0.06	0.02	-0.00	-0.39	0.72	-0.40	-0.04	0.79	28.2	1.99
		t-stat.	(9.95)	(-1.71)	(-0.25)	(-1.04)	(2.17)	(-1.88)	(0.87)	(-0.07)	(-1.11)	(1.58)	(-0.85)	(-0.12)			
		lag	1	2	3	4	12	13	14	15	9	10	11	12			
(1.1) (b)	NSP	INN, T	1.07	0.01	-0.29	-0.02	-0.04	0.02	0.02	-0.02	---	---	---	---	0.82	44.4	1.98
		t-stat.	(9.08)	(0.05)	(-1.69)	(-0.14)	(-3.64)	(1.78)	(1.76)	(-1.66)							
		lag	1	2	3	4	9	10	11	12							
(1.1) (d)	NSP	INN, T	1.03	-0.04	-0.29	0.03	-0.04	0.01	0.03	-0.03	0.02	0.39	-0.94	0.40	0.82	31.6	1.98
		t-stat.	(8.72)	(-0.25)	(-1.70)	(0.24)	(-3.58)	(0.86)	(2.14)	(-2.52)	(0.06)	(0.73)	(-1.76)	(1.17)			
		lag	1	2	3	4	9	10	11	12	9	10	11	12			
			b2	b2	b2	b2	a2	a2	a2	a2	c2	c2	c2	c2			
(2) (a)	Pat	NSP, T	0.96	-0.22	0.20	-0.13	---	---	---	---	---	---	---	---	0.70	55.7	2.07
		t-stat.	(9.29)	(-1.58)	(1.62)	(-1.65)											
		lag	1	2	3	4											
(2) (b)	Pat	NSP, T	0.87	-0.23	0.27	-0.07	-1.22	0.36	0.67	-0.47	---	---	---	---	0.71	30.1	1.98
		t-stat.	(8.12)	(-1.64)	(2.17)	(-0.84)	(-2.28)	(0.48)	(0.90)	(-0.93)							
		lag	1	2	3	4	1	2	3	4							
(2) (c)	Pat	NSP, T	1.03	-0.34	0.38	-0.26	---	---	---	---	-0.75	3.80	-5.32	2.46	0.72	28.0	1.96
		t-stat.	(9.34)	(-2.29)	(2.48)	(-2.19)					(-0.46)	(1.71)	(-2.31)	(1.55)			
		lag	1	2	3	4					10	11	12	13			
(2) (d)	Pat	NSP, T	0.95	-0.33	0.40	-0.16	-1.38	0.95	0.16	-0.39	-0.88	4.59	-5.49	1.90	0.73	19.7	1.98
		t-stat.	(8.17)	(-2.24)	(2.66)	(-1.22)	(-2.36)	(1.17)	(0.19)	(-0.70)	(-0.53)	(2.03)	(-2.31)	(1.17)			
		lag	1	2	3	4	1	2	3	4	10	11	12	13			

still Table 2: United Kingdom

Equation No.	Dependent Variable	Increm. Variable	Coefficient of Lagged Dep. Variable				Coefficient of First Incremental Variable				Coefficient of Second Variable				$\bar{R}^2$	F	D.W
			b2	b2	b2	b2	a2	a2	a2	a2	c2	c2	c2	c2			
(2.1) (a)	Inn	NSP, T	0.60	0.08	-0.03	-0.24	---	---	---	---	---	---	---	---	0.41	14.6	2.08
		t-stat.	(5.35)	(0.63)	(-0.20)	(-2.12)											
		lag	1	2	3	4											
(2.1) (b)	Inn	NSP, T	0.62	0.09	-0.07	-0.19	0.41	0.42	-2.21	1.79	---	---	---	---	0.39	7.5	2.13
		t-stat.	(5.35)	(0.61)	(-0.48)	(-1.54)	(0.34)	(0.23)	(-1.24)	(1.60)							
		lag	1	2	3	4	7	8	9	10							
(2.1) (c)	Inn	NSP, T	0.65	-0.03	-0.03	-0.24	---	---	---	---	-6.47	6.89	1.98	-3.98	0.41	8.7	2.14
		t-stat.	(5.64)	(-0.20)	(-0.19)	(-2.05)					(-1.84)	(1.29)	(0.38)	(-1.18)			
		lag	1	2	3	4					1	2	3	4			
(2.1) (d)	Inn	NSP, T	0.67	-0.04	-0.05	-0.18	1.08	-0.24	-1.60	1.59	-5.57	6.29	2.46	4.85	0.40	5.4	2.17
		t-stat.	(5.37)	(-0.23)	(-0.34)	(-1.29)	(0.83)	(-0.13)	(-0.89)	(1.36)	(-1.48)	(1.12)	(0.44)	(1.25)			
		lag	1	2	3	4	7	8	9	10	1	2	3	4			
			c3	c3	c3	c3	a3	a3	a3	a3	b3	b3	b3	b3			
(3) (a)	T	NSP, PAT	1.01	0.37	-0.26	-0.24	---	---	---	---	---	---	---	---	0.95	491.6	2.01
		t-stat.	(9.83)	(2.55)	(-1.77)	(-2.33)											
		lag	1	2	3	4											
(3) (b)	T	NSP, PAT	1.05	0.32	-0.29	-0.20	0.06	-0.13	0.15	-0.07	---	---	---	---	0.96	265.5	1.98
		t-stat.	(10.10)	(2.20)	(-2.07)	(-1.87)	(1.57)	(-2.59)	(2.87)	(-1.88)							
		lag	1	2	3	4	3	4	5	6							
(3) (c)	T	NSP, PAT	1.01	0.40	-0.25	-0.27	---	---	---	---	-0.00	-0.00	0.00	0.01	0.95	219.7	2.03
		t-stat.	(9.33)	(2.58)	(-1.63)	(-2.49)					(-0.32)	(-0.25)	(0.08)	(0.82)			
		lag	1	2	3	4					8	9	10	11			
(3) (d)	T	NSP, PAT	1.05	0.35	-0.28	-0.25	0.06	-0.12	0.16	-0.09	-0.01	-0.01	0.00	0.01	0.96	161.7	2.06
		t-stat.	(9.66)	(2.29)	(-1.86)	(-2.18)	(1.60)	(-2.24)	(2.86)	(-2.14)	(-0.83)	(-0.46)	(0.30)	(1.00)			
		lag	1	2	3	4	3	4	5	6	8	9	10	11			
(3.1) (c)	T	NSP, INN	1.05	0.32	-0.25	-0.22					0.00	-0.00	0.01	-0.00	0.96	215.9	2.01
		t-stat.	(9.01)	(1.94)	(-1.53)	(-1.97)					(0.81)	(-0.89)	(1.44)	(-0.36)			
		lag	1	2	3	4					6	7	8	9			
(3.1) (d)	T	NSP, INN	1.11	0.25	-0.29	-0.18	0.06	-0.15	0.16	-0.07	0.00	-0.01	0.01	-0.00	0.96	153.3	1.98
		t-stat.	(9.16)	(1.49)	(-1.81)	(-1.47)	(1.29)	(-2.63)	(2.76)	(-1.60)	(0.71)	(-1.24)	(1.60)	(-0.41)			
		lag	1	2	3	4	3	4	5	6	6	7	8	9			

Notes: The figures in paratheses are t statistics. - D.W denotes Durbin-Watson-statistics.

Source: Own calculations.

Table 3: Granger Test Estimates on Scientific-Technical Progress and Economic Development: USA

Equation No.	Dependent Variable	Increm. Variable	Coefficient of Lagged Dep. Variable				Coefficient of First Incremental Variable				$\bar{R}^2$	F	D.W
			a1	a1	a1	a1	b1	b1	b1	b1			
(1) (a)	NSP	Pat,	1.07	-0.19	-0.18	0.01	---	---	---	---	0.71	48.3	1.77
		t-stat.	(9.31)	(-1.18)	(-1.11)	(0.12)							
		lag	1	2	3	4							
(1) (b)	NSP	Pat,	1.10	-0.21	-0.20	0.00	-0.00	-0.01	0.18	-0.13	0.72	26.1	1.81
		t-stat.	(9.66)	(-1.35)	(-1.26)	(0.34)	(-0.65)	(-0.78)	(2.33)	(-2.28)			
		lag	1	2	3	4	17	18	19	20			
(1.1) (b)	NSP	INN,	1.05	-0.02	-0.44	0.10	-0.07	0.04	0.03	-0.02	0.70	23.2	1.88
		t-stat.	(8.25)	(-0.12)	(-2.47)	(0.78)	(-2.76)	(1.11)	(0.74)	(-0.93)			
		lag	1	2	3	4	7	8	9	10			
			b2	b2	b2	b2	a2	a2	a2	a2			
(2) (a)	Pat	NSP,	0.84	-0.18	0.09	-0.11	---	---	---	---	0.52	23.4	2.03
		t-stat.	(7.54)	(-1.23)	(0.58)	(-1.01)							
		lag	1	2	3	4							
(2) (b)	Pat	NSP,	0.81	-0.14	0.09	-0.17	-0.08	-0.28	0.53	0.01	0.54	13.1	2.05
		t-stat.	(6.98)	(-0.93)	(0.58)	(-1.48)	(-0.36)	(-0.94)	(1.68)	(0.06)			
		lag	1	2	3	4	10	11	12	13			
(2.1) (a)	Inn	NSP,	0.77	-0.00	-0.00	-0.21	---	---	---	---	0.55	25.0	2.13
		t-stat.	(6.84)	(-0.03)	(-0.03)	(-1.86)							
		lag	1	2	3	4							
(2.1) (b)	Inn	NSP,	0.77	0.01	-0.04	-0.20	0.34	-0.25	-1.12	1.17	0.56	13.5	2.05
		t-stat.	(6.92)	(0.10)	(-0.26)	(-1.71)	(0.62)	(-0.34)	(-1.56)	(2.23)			
		lag	1	2	3		4	5	6	7			

Notes: The figures in paratheses are t statistics. - D.W denotes Durbin-Watson-statistics.

Source: Own calculations.

Table 4: A Granger-Causality Test: Scientific-Technical Progress and Economic Development

No.	Comparison between equations	F-statistics[a]	Results[b]	Lag
		GERMANY		
1	1 a and 1 b	0.07	Pat ⇏ NSP	---
2	1 a and 1 c	1.66	T ⇏ NSP	---
3	1 b and 1 d	1.71**	(PAT) T ⇒ NSP	4
4	1 c and 1 d	0.14	(T) PAT ⇏ NSP	---
5	1.1 a and 1.1 b	0.52	INN ⇏ NSP	---
6	2 a and 2 b	2.01**	NSP ⇒ PAT	3
7	2 a and 2 c	2.58*	T ⇒ PAT	4
8	2.1 a and 2.1 b	0.59	NSP ⇏ INN	---
9	2.1 a and 2.1 c	0.21	T ⇏ INN	---
10	2 b and 2 d	1.67**	(NSP) T ⇒ PAT	4
11	2 c and 2 d	1.07	(T) NSP ⇏ PAT	---
12	3 a and 3 b	0.14	NSP ⇏ T	---
13	3 a and 3 c	0.28	PAT ⇏ T	---
14	3.1 a and 3.1 c	4.59*	INN ⇒ T	9;10
15	3 b and 3 d	0.26	(NSP) PAT ⇏ T	---
16	3 c and 3 d	0.09	(PAT) NSP ⇏ T	---
		UNITED KINGDOM		
1	1 a and 1 b	1.49	PAT ⇏ NSP	---
2	1 a and 1 c	1.12	T ⇏ NSP	---
3	1 b and 1 d	0.98	(PAT) T ⇏ NSP	---
4	1 c and 1 d	1.33	(T) PAT ⇏ NSP	---
5	1.1 a and 1.1 b	4.05*	INN ⇒ NSP	9;10;11;12
6	2 a and 2 b	2.04**	NSP ⇒ PAT	1
7	2 a and 2 c	1.79**	T ⇒ PAT	11;12
8	2.1 a and 2.1 b	0.64	NSP ⇏ INN	---
9	2.1 a and 2.1 c	1.43	T ⇏ INN	---
10	2 b and 2 d	1.86**	(NSP) T ⇒ PAT	11;12
11	2 c and 2 d	1.55	(T) NSP ⇏ PAT	---
12	3 a and 3 b	2.67*	NSP ⇒ T	4;5;6
13	3 a and 3 c	0.29	PAT ⇏ T	---
14	3.1 a and 3.1 c	0.79	INN ⇏ T	---
15	3 b and 3 d	0.71	(NSP) PAT ⇏ T	---
16	3 c and 3 d	2.94*	(PAT) NSP ⇒ T	4;5;6

still Table 4: A Granger-Causality Test: Scientific-Technical Progress and Economic Development

No.	Comparison between equations	F-statistics[a]	Results[b]	Lag
		USA		
1	1 a and 1 b	1.81**	PAT ⟹ NSP	19;20
2	1.1 a and 1.1 b	2.01**	INN ⟹ NSP	7
3	2 a and 2 b	1.81**	NSP ⟹ PAT	12
4	2.1 a and 2.1 b	1.38	NSP ⇏ INN	---

[a] * denotes significant at 5 % level; ** denotes significant at the 10 % level. - [b] ⟹ denotes Granger causality and direction; ⇏ denotes no Granger causality. (PAT) T denotes technological gap with given patenting; (T) PAT denotes patenting with given technological gap. In the same vein: ((NSP) T; (T) NSP; (NSP) PAT; (PAT) NSP.

Source: Own calculations.