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Innovation, Standardisation and the Long-term Production Function

A Cointegration Analysis for Germany 1960 – 1996*

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1. Introduction

The significance of technological activities as an essential determinant of the economic performance of industrialised economies is generally acknowledged today. It is also undisputed in the meantime that technical standards are very important for the fast diffusion of new technologies. In clear contradiction to the theoretical insights and economic relevance, however, is the consideration of the level of technology, resp. the technological progress, and the role of standardisation in macroeconometric production models. So when estimating production functions (e.g. a Cobb-Douglas production function), technological progress is commonly approximated by a simple linear time trend. This procedure has a series of weaknesses. On the one hand, the inclusion of a time trend does not provide an explanation for technical changes, i. e. the causes or sources underlying technical progress are not distinguishable. At most, the order of magnitude of the technical progress can be estimated. On the other hand, no changes in the rate of technical progress can be identified. Rather, technical progress grows uniformly, as if dropping from heaven. Only a few authors have taken technical progress into account by using more appropriate indicator variables (Budd / Hobbis, 1989; Budd / Hobbis, 1989a and Coe / Moghadam, 1993). A formal record of the influence of standardisation in macroeconometric production functions by means of appropriate indicator variables is – to our knowledge – completely missing. Only one study presents an econometric analysis of the effects of standards on UK trade performance (Swann / Temple / Shurmer, 1996).

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In the present study alternative sources of technical progress will be identified and approximated by means of indicator variables (see Section 2). The theoretical reference model for technical progress – as a true theory of innovation is still lacking – is borrowed from Grupp (1998, chapter 1). We shall distinguish between technical progress which is the result of own inventive achievements, and the import of technological know-how through licensing agreements. The first source of technical progress will be approximated by the time lagged stock of patents at the German Patent Office (Deutsches Patentamt), the second by the real fees for licences from the balance of payments of the Federal Republic of Germany. In addition, the role of standardisation in facilitating technology diffusion will be integrated in the long-term production function. It will be approximated by the stock of effective technical standards registered at the database PERINORM edited by the German, French and British standards organisations.

For estimating the long-term production functions, the concept of the cointegration of time series introduced by Engle / Granger (1987) will be used. As we consider only the long-term relations and not the short-term dynamics between the output, the usual production factors and the indicator variables for technical progress, as well as for the role of standardisation, only the first step of the Engle-Granger two-step procedure will be applied, in which existing long-term relations are identified and estimated without specifying the short-term dynamics (see Section 3). However, the distribution of the estimators of the cointegrating vector provided by such a static regression is generally non-normal and so inference cannot be drawn about the significance of the individual parameters by using the standard t tests. For this reason the three-step procedure, proposed by Engle / Yoo (1991), is subsequently used to remedy this shortcoming. Their third step, added to the Engle-Granger two-step procedure, provides a correction to the parameter estimates of the first stage static regression which makes them asymptotically equivalent to full information maximum likelihood (FIML) estimates and provides a set of standard errors which allows the valid calculation of standard t tests.

The superior long-term production function will be used (refer to Section 4) to assess the effects of technical progress as approximated by the indicator variables and of the role of standardisation, as approximated by the stock of technical standards, as well as the impact of the usual production factors on economic growth (cf. e.g. Jungmittag / Welfens, 1996 for a similar analysis without modelling standards as an indicator for technology diffusion).

2. Production Functions, Technological Innovation and Standardisation

Our starting point is the usual Cobb-Douglas production function

$$(1) \qquad Y_t = A \cdot K_t^{\alpha} \cdot L_t^{\beta} \cdot e^{\lambda \cdot t} \ ,$$

where Y_t represents the output, K_t the capital employed and L_t the amount of labour. The parameters α and β represent the partial production elasticities of capital and labour. Technical progress is usually taken into account in the Cobb-Douglas production function in an unembodied and neutral form, with the efficiency parameter A determined by the equation $A(t) = A \cdot e^{\lambda \cdot t}$. In logarithmic form the production function can then be written as

$$(2) \qquad y_t = a + \alpha \cdot k_t + \beta \cdot l_t + \lambda \cdot t \ ,$$

where lower case letters denote logarithms.

At a first glance the use of a linear time trend to record technical progress appears to be an admissible simplification. However, this procedure reveals a series of weaknesses.[1] On the one hand, the inclusion of a time trend does not provide an explanation for technological changes, i.e. the causes or sources underlying technical progress are not distinguishable. At most, the order of magnitude of technical progress can be estimated. On the other hand, when using a time trend, no changes in the rate of technical progress can be identified. Rather, technical progress grows uniformly, as if dropping from heaven. These weaknesses can be remedied if the status of technology or of technical progress were approximated by appropriate indicators. To this end it is useful to distinguish alternative sources of technical progress (Grupp, 1998).

A central possibility to attain technical progress is represented by research and development (R&D) activities. It does not appear promising to include the R&D expenditures directly in a production model. As Kennedy / Thirlwall (1972) already emphasised, the immense growth of expenditure on R&D appears to have only small effects on the aggregate growth rates on a country level. This is not surprising, however: Since R&D is an investment flow, the output of the enterprises is affected by the accumulated stock of earlier results of such investments and of other knowledge sources apart from explicit R&D activities (Griliches, 1980). In addition, R&D comprises basic (academic) and defence research as well as experimental devel-

1 Cf. Budd / Hobbis (1989), p. 2, on the weaknesses.

opment in industry, the productive effects of which, respectively, are quite different (Grupp, 1998, pp. 18–25). Therefore, apart from data-technical problems, the inclusion of a stock of R&D capital in the production function, as in Coe / Moghadam (1993), does not provide a suitable approximation for technical progress. A large stock of R&D capital is a necessary, but not a sufficient condition for technological innovations. Thus it is necessary to find an appropriate indicator for the stock of results of R&D activities. In this study the mean stock of patents in the German Patent Office is used as such an indicator. This patent stock at year's end is defined as

> stock at beginning of year + basic patents granted + granted additional patents – cancelled patents – lapsed patents.[2]

The mean stock of patents, pat_t, is then calculated as the average of the patent stocks at previous year's end and at current year's end. As a certain period will elapse between the granting of a patent and the full implementation of the respective innovation in the companies, this indicator is to be taken into account in the empirical investigations with an appropriate time lag. In accordance with other empirical investigations (Griliches / Lichtenberg, 1984; Griliches / Mairesse, 1984; Geroski, 1991; Münt, 1996 and Grupp / Jungmittag, 1999), our empirical examinations showed that a time lag of three years elapses before production is affected.

A further possibility to utilise technological innovations are licensing agreements with foreign companies. This import of technological know-how will always be worthwhile if it is cheaper and / or faster than the own development of corresponding technologies (Budd / Hobbis, 1989a, p. 5). The expenditure for licences and patents, lex_t, from the balance of payments of the Federal Republic of Germany will be taken as an indicator for this source of technical progress.[3] Although these payments are mainly transacted between affiliated firms and so influenced by transfer price settings, they give quite general evidence about the trends of technology transfer mainly due to foreign direct investment (Beise / Belitz, 1996, p. 60). As this data is only available in respective prices, it was deflationed with the price index for gross fixed capital formation on the basis of 1991. Although this price index will only imprecisely reflect the price development for expenditure on li-

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[2] Cf. Statistisches Bundesamt (different years). The patent data from 1963 to 1996 were taken from the Statistical Yearbook of the Statistisches Bundesamt and from the Blatt für Patent-, Muster- und Zeichenwesen (1998, Heft 3). The non-available values (from 1957 to 1962) were estimated on the basis of a linear trend.

[3] This data was also taken from the Statistical Yearbook of the Statistisches Bundesamt, and from Deutsche Bundesbank (1998). These expenditures comprise fees for the current use as well as the purchase of patents, inventions, procedures and other property rights like trademarks, utility-model and design patents. However, movie rights are not included in these property rights (Deutsche Bundesbank, 1998, p. 21).

cences, it should be the most adequate among the available price indexes (Budd / Hobbis, 1989, p. 15).

Besides patents, technical standards are also an appropriate indicator for the stock of results of research and development activities. Traditionally, technical standards have three different main economic functions (Swann / Temple / Shurmer, 1996, p. 1298). First, as compatibility standards, they allow products or components of products to work together. Secondly, they define a certain level of product or process quality in the form of minimum quality standards. Thirdly, they reduce the number of variants in a product range – a variety reduction standard. Therefore, technical standards are an indicator for the technological capability of an economy. The variety-reduction-type standard can lead to scale effects and thus fosters diffusion – which is certainly more relevant to overall productivity than (initial) innovation.

The PERINORM, available on CD-ROM contains all technical standards[4] in Germany among other European nations, including technical regulations since the mid seventies.[5] The stock of standards at a year's end is defined as

> stock at beginning of year + new technical standards published
> – technical standards withdrawn.

The mean stock of patents, std_t, is also calculated as the average of the stocks of standards at previous year's end and at current year's end. Because of the years which elapse between the beginning of a standardisation process and preliminary publication as a prestandard and the final publication of the document, the companies in general do not have a time lag in getting aware and implementing the results of the standards. Thus, no time lag seems to be required for this variable.

With the technological innovations and the role of standardisation explicitly taken into consideration, the extended Cobb-Douglas production function is in logarithmic form:

$$(3) \qquad y_t = a + \alpha \cdot k_t + \beta \cdot l_t + \gamma \cdot pat_{t-3} + \delta \cdot lex_t + \varepsilon \cdot std_t + u_t \ .$$

We assume that the error term fulfils the usual assumptions. In the course of the empirical analysis various variants of this function for the German business sector were estimated, with real gross value-added as endogenous variable. The capital stock for this sector was determined in the usual way

[4] The stock of standards also includes European and international standards adopted by Germany.

[5] This means that the stock of standards before the mid seventies is slightly underestimated. Technical regulations are of marginal importance in Germany, except in the field of the environment and safety.

as in the annual average employed gross fixed assets in 1991 prices. The number of employees in this sector of the economy was taken as labour input variable.[6] Other input variables, such as the number of hours worked, were not available for the complete sample period.

While the usual time series which are used to estimate the production functions refer to the business sector without the atypical fields of agriculture, forestry, fishing and flat rentals, the selected indicators for the technological innovations and standardisation encompass the economy as a whole. For these indicators there are no time series available which refer to the individual economic sectors. They are likewise not easily established by online patent statistics, as the concordance problem between patent classification and sector definition is very difficult to solve (Grupp, 1998, pp. 162–163). As these atypical sectors have anyway benefited very little from technological innovations, we assume that the distortion is negligible.

It is often assumed in empirical investigations that the scale elasticity of the factors capital and labour is equal to unity, i. e. $\alpha = 1 - \beta$. This restriction can be very simply realised if the initial logarithmic production functions (2) and (3) are written as

(4) $$y_t - l_t = a + \alpha \cdot (k_t - l_t) + \lambda \cdot t + u_t$$

or

(5) $$y_t - l_t = a + \alpha(k_t - l_t) + \gamma \cdot pat_{t-3} + \delta \cdot lex_t + \varepsilon \cdot std_t + u_t \ .$$

The admissibility of such a restriction of the scale elasticity can be tested by means of an F test.

3. Non-stationarity of Time Series and Cointegration

Many macroeconomic variables contain stochastic trends. However, certain linear combinations of them may be stationary. Based on economic theory, such long-term connections can often be interpreted as equilibrium relationships. This economic concept of equilibrium corresponds to the statistical concept of cointegration.[7] Engle / Granger (1987) showed that cointegrated time series have an error correction representation. Let us consider a Var(p) model for N time series which can be written as

6 All data mentioned here was taken from the national accounts statistics of the Statistisches Bundesamt (1998).

7 For more details of non-stationarity of time series and cointegration refer to, among others, Jungmittag (1996).

(6) $$\mathbf{z}_t = \mathbf{v} + \sum_{i=1}^{p} \mathbf{A}_i \mathbf{z}_{t-i} + \mathbf{e}_t \ .$$

This model can be reparametrised as an error correction model

(7) $$\Delta \mathbf{z}_t = \mathbf{v} + \mathbf{A}_0 \mathbf{z}_{t-1} + \sum_{i=1}^{p-1} \mathbf{A}_i^* \Delta \mathbf{z}_{t-i} + \mathbf{e}_t$$

with $$\mathbf{A}_i^* = -\sum_{j=i+1}^{p-1} \mathbf{A}_j \ , \quad i = 1, 2, \ldots, p-1$$

and $$\mathbf{A}_0 = \sum_{j=1}^{p} \mathbf{A}_j - \mathbf{I}_N \ .$$

The matrices of coefficients corresponding to the first differences capture the short term dynamics while the matrix $\mathbf{A}_0$ contains information about the long-term relations between the variables.

Furthermore, Engle / Granger (1987) showed that an error correction model can be estimated in a two-step procedure by least squares regression. In the first step the cointegration vector which represents the long-term relations is estimated without modelling the short-term dynamics. In the second step the lagged residuals of the long-term relation are used as an error correction term and the short-term dynamics are specified.

In this study, only the long-term relations are of interest. Static OLS regression provides consistent estimators of the cointegration vector, but these estimates are generally not normally distributed, and so the usual t statistics cannot be used for statistical inferences about the significance of the individual cointegration parameters (Cuthbertson / Hall / Taylor, 1992, pp. 140 – 141; Engle / Granger, 1991, p. 10). So, an isolated examination of the significance of the influence of the indicator variables capturing technological progress would be impossible. Both disadvantages can be surmounted when the three-step procedure from Engle / Yoo (1991) is used. In this procedure Engle and Granger's two-step procedure is supplemented by a third step, which contains a correction of the parameter estimates so that they are asymptotically equal to FIML estimates. Furthermore, the third step provides standard deviations which can be used to compute the usual t statistics.[8]

[8] The three-step procedure by Engle and Yoo provides a computationally rather simple, feasible alternative to system methods of estimation like the test and estimation procedure proposed by Johansen (cf. e. g. Johansen, 1988 and Johansen, 1991), which estimate simultaneously the long-term relations and the short-term dynamics. Without a complete modelling of the short-term dynamics of all time series consid-

If, in the first step, the parameters of the cointegration relation $\boldsymbol{\alpha}_1$ are estimated by means of the static regression

$$y_t = \boldsymbol{\alpha}_1'\mathbf{x}_t + q_t \ , \tag{8}$$

where q_t is the OLS residual term, and in the second step the dynamic error correction model

$$\Delta y_t = \beta(L)\Delta y_{t-1} + \boldsymbol{\Gamma}(L)\boldsymbol{\Delta}\mathbf{x}_t + \delta q_{t-1} + u_t \tag{9}$$

is specified and estimated using these OLS residuals, then the third step consists of a regression of the lagged explanatory variables, multiplied by the error correction coefficient δ which was before multiplied by – 1, of the static regression on the error term u_t of the model from the second step, i. e.:

$$u_t = \boldsymbol{\varepsilon}'(-\delta\mathbf{x}_{t-1}) + v_t \ . \tag{10}$$

The correction of the estimates is then carried out by

$$\boldsymbol{\alpha}_3 = \boldsymbol{\alpha}_1 + \boldsymbol{\varepsilon} \ , \tag{11}$$

and the correct standard errors of $\boldsymbol{\alpha}_3$ correspond to the standard errors of $\boldsymbol{\varepsilon}$ from the regression in the third step.

4. Empirical Results

The starting point of the empirical investigation is a univariate analysis of the time series under consideration (figure 1). Nearly all time series show permanent growth over time. The only exception is log of employees which is strongly influenced by business cycles. Furthermore, a strong increase of employment can be observed in the second half of the eighties. Additionally, the time series of real gross value added as well as of the production factors capital and labour show a break in 1990 / 1991 due to German unification. Also obvious is the strong increase of the real licence expenditures in the first half of the eighties and again in 1995 / 1996. The transformed variables, which are used in the restricted production functions, where the sum of the production elasticities of the factors labour and capital is set to equal unity,

ered which could be an excessive demand for the available 37 annual observations and therefore would destroy the theoretical advantages, the three-step estimates have the same limiting distribution as the FIML estimates. This argument holds also in the case of an ECM estimation, because this procedure would decrease the degrees of freedom dramatically too.

are displayed in figure 2. These time series are also growing rather uniformly, but the increases are not so strong as the increases of the original time series. Again, a break due to German unification can be observed.

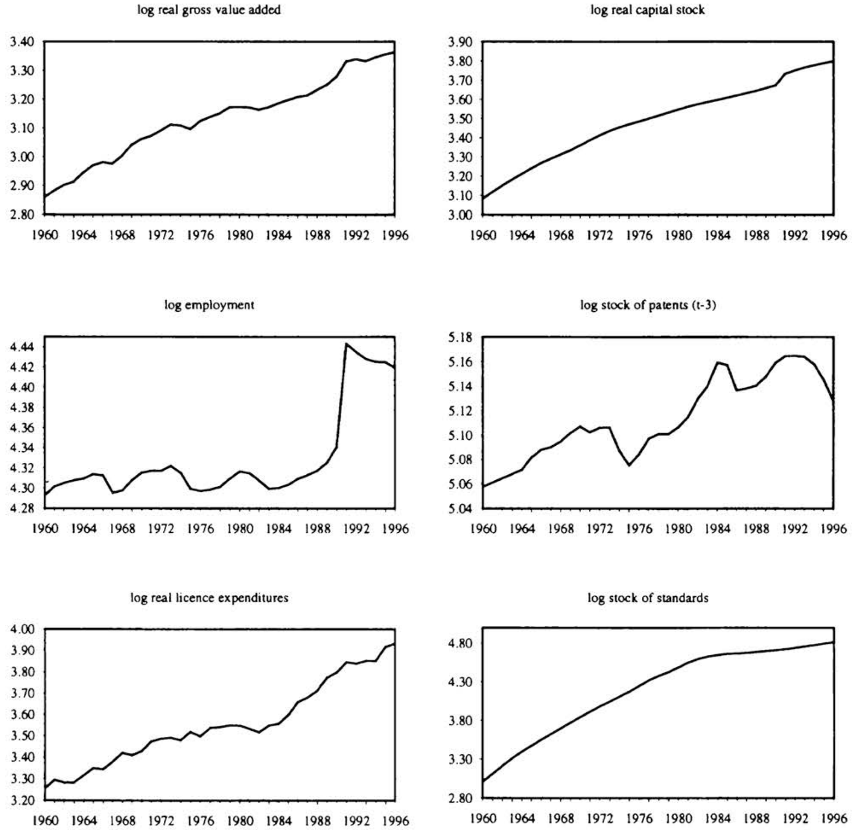

Figure 1: Variables used for the unrestricted production function, 1960 – 1996

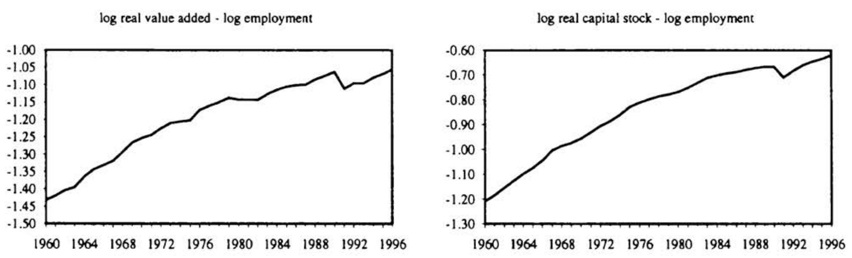

Figure 2: Variables used for the restricted production function, 1960 – 1996

In order to check whether the time series are integrated of order one (i.e. the series are characterised by unit roots) or whether they are following deterministic trends, ADF tests were carried out. The null hypothesis of a unit root cannot be rejected for any of the eight variables. For the first differences the null hypothesis must be rejected at a significance level of at least 5 %. So, it can be concluded that all individual time series are I(1).

Table 1

Estimation results for the simple production function

Variable	First step of Engle / Granger		Third step of Engle / Yoo	
	unrestricted	$\hat{\alpha}+\hat{\beta}=1$	unrestricted	$\hat{\alpha}+\hat{\beta}=1$
Constant	– 2.411	– 0.833	– 2.436	– 0.872
	(– 5.055)[a)]	(– 14.288)	(– 9.318)	(– 9.986)
k_t	0.559	0.501	0.614	0.468
	(12.287)	(10.317)	(12.181)	(6.466)
l_t	0.824	0.499	0.790	0.533
	(7.747)	–	(13.802)	–
t	0.003	0.004	0.002	0.005
	(2.816)	(3.987)	(1.727)	(3.063)
DOC	-0.016	– 0.019	– 0.013	– 0.019
	(– 3.653)	(– 3.819)	(– 3.250)	(– 2.809)
D80	-0.014	– 0.014	– 0.015	– 0.015
	(– 2.270)	(– 1.932)	(– 2.621)	(– 1.505)
D81	-0.017	– 0.022	– 0.017	– 0.026
	(– 2.665)	(– 3.027)	(– 2.883)	(– 2.500)
DGU	-0.067	0.032	– 0.062	– 0.034
	(– 5.374)	(– 4.183)	(– 8.690)	(– 3.120)
R^2	0.999	0.997	0.999	0.997
$R^2_{adj.}$	0.998	0.997	0.998	0.996
DW test	1.565	1.357	–	–
LM serial	3.330	5.328		
correlation test χ^2 (4)	(0.504) [c)]	(0.255)		
EG test	(36, 3)[b)]	(36, 2)	–	–
	– 5.070	– 4.141	–	–
	(0.011)[c)]	(0.041)	–	–
F test of the			10.000	
restriction			(0.004)[c)]	

a) Empirical t values in brackets but statistical conclusions on the base of usual t tests are only permitted if the third step of the Engle / Yoo procedure has been applied.
[b)] Number of observations available after forming lags and first differences and number of $I(1)$ variables in brackets.
[c)] Significance levels in brackets.

In the next step the unrestricted and restricted version of the simple Cobb-Douglas production function was estimated, where technical progress is approximated by a linear time trend. Besides the capital stock and employment, these functions include the dummy variables *DOC* which captures the first West German depression in 1967 and the first oil crisis, as well as *D80* and *D81* which capture a structural break starting in 1980 and reinforcing in 1981 following the second oil crisis. Furthermore, a dummy variable *DGU* is added to the equation to catch the effects of German unification.[9]

The estimation results are displayed in table 1. The estimates of the coefficients show the expected signs and the magnitude of the partial production elasticities is as expected. The R^2 values of 0.999 resp. 0.997 indicate a very good fitting of the models to the observed data. However, it must be taken into account that the R^2 values of the unrestricted and the restricted model cannot be compared immediately because they are based on different total sums of squares. Concerning the possibility of serial correlation the test results are not unambiguous. The *DW* test statistics suggest for both models in the case of a two-sided test that a decision on first order autocorrelation is not possible at a significance level of 5 %, but the *LM* tests provide no evidence for serial correlation up to lag 4. Furthermore, the null hypothesis of no cointegration relation of the *EG* test can be rejected at least at 5 %, indicating that they can be interpreted as long-term production functions. However, the *F* test of the restriction $\alpha + \beta = 1$ indicates clearly that this hypothesis must be rejected.

The simple production function was re-specified in such a manner that the time trend was substituted by the three indicator variables. The estimation results for the unrestricted and restricted version of this long-term production function are reported in table 2. The t values calculated for the estimates of the third step of the Engle / Yoo procedure show that all coefficients of the unrestricted as well as the restricted estimation are unequal to zero at least at a significance level of 5 %. Therefore, all three indicator variables have a highly significant power of explanation. Furthermore, the magnitudes of their coefficients verify that the factors approximated by the indicator variables make contributions to real gross value added that cannot be neglected.

The estimates of the coefficients of the factors capital and labour also seem to be very reliable. They are rather similar to the estimates in Schröer / Stahlecker (1996) where a long-term Cobb-Douglas production function is estimated using quarterly data from 1970 until 1994. Schröer /

9 In concordance with Schröer / Stahlecker (1996), we find no shifts of the production elasticities of the factors capital and labour after German unification.

Stahlecker (1996) introduced, after a data mining process, dummy variables which change the slope of the time trend to approximate changes of technical progress.

Table 2

Estimation results for the augmented production function

Variable	First step of Engle / Granger		Third step of Engle / Yoo	
	unrestricted	$\hat{\alpha}+\hat{\beta}=1$	unrestricted	$\hat{\alpha}+\hat{\beta}=1$
Constant	-2.399	– 2.304	– 2.626	– 2.484
	(– 4.739)[a)]	(– 5.831)	(– 8.975)	(– 8.799)
k_t	0.387	0.361	0.416	0.360
	(2.933)	(3.642)	(5.175)	(6.100)
l_t	0.662	0.639	0.652	0.640
	(5.321)	–	(10.935)	–
pat_{t-3}	0.119	0.127	0.166	0.160
	(1.493)	(1.689)	(3.360)	(3.269)
lex_t	0.129	0.137	0.121	0.139
	(3.692)	(6.017)	(5.532)	(8.817)
std_t	0.063	0.070	0.055	0.071
	(1.739)	(2.396)	(2.405)	(4.000)
DOC	-0.017	– 0.017	– 0.016	– 0.016
	(– 4.026)	(– 4.114)	(– 6.154)	(– 6.320)
D80	-0.011	– 0.011	– 0.010	– 0.012
	(– 1.756)	(– 1.802)	(– 2.539)	(– 3.132)
D81	-0.017	– 0.017	– 0.018	– 0.019
	(– 2.597)	(– 2.730)	(– 4.816)	(– 5.053)
DGU	-0.038	– 0.034	– 0.039	– 0.034
	(– 2.765)	(– 6.418)	(– 8.750)	(– 9.189)
R^2	0.999	0.998	0.999	0.998
$R^2_{adj.}$	0.999	0.998	0.999	0.998
DW test	2.144	2.184	–	–
LM serial	3.447	3.595		
correlation test χ^2 (4)	(0.486) [c)]	(0.464)		
EG test	(36, 6)[b)]	(36, 5)	–	–
	– 6.965	– 7.026	–	–
	(0.004)[c)]	(0.002)	–	–
F test of the			1.350	
restriction			(0.255)[c)]	

a) Empirical *t* values in brackets but statistical conclusions on the base of usual *t* tests are only permitted if the third step of the Engle / Yoo procedure has been applied.
[b)] Number of observations available after forming lags and first differences and number of I(1) variables in brackets.
[c)] Significance levels in brackets.

Table 3

Estimation results for the hybrid production function

Variable	First step of Engle / Granger	Third step of Engle / Yoo
Constant	-2.450	– 2.858
	(– 4.690)[a)]	(– 9.156)
k_t	0.362	0.489
	(2.552)	(4.830)
l_t	0.701	0.634
	(4.780)	(9.080)
pat_{t-3}	0.127	0.186
	(1.539)	(3.669)
lex_t	0.107	0.127
	(1.897)	(4.596)
std_t	0.062	0.041
	(1.679)	(1.700)
t	0.001	– 0.001
	(0.521)	(– 0.818)
DOC	-0.016	– 0.015
	(– 3.472)	(– 5.519)
D80	-0.013	– 0.009
	(– 1.745)	(1.932)
D81	-0.018	– 0.017
	(– 2.502)	(– 3.689)
DGU	-0.042	– 0.041
	(– 2.689)	(– 8.848)
R^2	0.999	0.999
$R^2_{adj.}$	0.999	0.998
DW test	2.042	
LM serial correlation test χ^2 (4)	2.428	
	(0.658)[c)]	
EG test	(36, 6)[b)]	
	– 6.523	
	(0,009)[c)]	

a) Empirical t values in brackets but statistical conclusions on the base of usual t tests are only permitted if the third step of the Engle / Yoo procedure has been applied.
[b)] Number of observations available after forming lags and first differences and number of I(1) variables in brackets.
[c)] Significance levels in brackets.

Once the estimation and testing phase is finished, the question arises whether the augmented production function is superior to the simple production function. A direct comparison can be carried out only for the unrestricted estimates because the restriction of the production elasticities was rejected for the simple production function. On principle, there are two possibilities to evaluate the estimation results. First, some statistical measures yielded during the estimation and specification phase can be used in a descriptive manner. Here, the adjusted R^2 values indeed suggest that the augmented production function is superior. Applying the third step of the Engle / Yoo procedure an adjusted R^2 of 0.999 is realised for the augmented production function while it is 0.998 for the simple production function with a time trend. The superiority of the augmented production function becomes even more obvious when the residual sums of squares resp. the standard deviations of the residuals are compared. The residual sum of squares amounts to 0.000740 for the three-step estimation of the augmented production function, while it amounts to 0.001073 for the simple production function. Thus, the reduction of the residual sums of squares is 31 %. The comparison of the standard deviations of the residuals which takes the different degrees of freedom of the two estimates into account provides a similar picture. The standard deviation is 0.0052 for the augmented production function and 0.0061 for the simple production function. Thus, its reduction amounts to 14 %.

Secondly, a hybrid model including the three indicator variables as well as the time trend was estimated to test the simple against the augmented production function. The results are reported in table 3. They also confirm the previous conclusions. All three indicator variables continue to be at least at a significance level of 5 % greater than zero, but the time trend is now not significantly different from zero.

Table 4

Sources of growth in the business sector, 1961 – 1996

Source	Average annual percentage changes							
	61 – 90	61 – 65	66 – 70	71 – 75	76 – 80	81 – 85	86 – 90	92- 96
k_t	1.6	2.6	2.0	1.7	1.3	0.8	1.1	1.1
l_t	0.2	0.6	0.1	– 0.6	0.5	– 0.6	1.1	– 0.7
pat_{t-3}	0.1	0.2	0.2	– 0.4	0.3	0.2	0.0	– 0.3
lex_t	0.5	0.6	0.5	0.4	0.2	0.1	1.3	0.6
std_t	0.9	1.5	1.2	0.9	1.1	0.4	0.2	0.3
Total:								
fitted	3.3	5.7	4.1	2.1	3.5	1.0	3.7	1.0
realised	3.3	5.2	4.4	1.7	3.6	1.1	3.8	1.5

Note: Differences between the sums of the individual components of the growth rates and the fitted total growth rates are caused by rounding and by joint effects.

Although only the unrestricted estimates can be compared directly, it can be concluded immediately that the restricted estimate of the production function with three indicator variables is also superior to the simple production function because the restriction is allowed and causes no reduction of the fitting of the unrestricted model. Therefore, this production function remains the superior specification.

Due to the approximation of different sources resp. causes of technical progress and of standardisation by means of appropriate indicator variables it is now possible to assess, at least roughly, the effects of these variables as well as of the usual production factors on the growth of real gross value-added. The results of the ex-post forecasts of average annual growth rates for the whole sample period before German unification as well as for different subperiods before and after German unification are reported in table 4. The comparison of the realised total and the forecasted total growth rates of real gross value-added in the business sector without agriculture, forestry, and fishing and without flat rental shows a good fit of the model to the data. Only in two subperiods (from 1961 until 1965 and from 1971 until 1975) the model overestimates the growth rates by 0.6 resp. 0.4 percentage points. In two subperiods (from 1966 until 1970 and from 1992 until 1996) it underestimates the growth rates by 0.3 resp. 0.5 percentage points. However, in three of these subperiods economic growth is strongly affected by exogenous influences, which are not fully captured by the dummy variables.

Turning to the individual factors, it can be seen that the development of the capital stock has the greatest impact on the growth rates of gross value added in most cases, accounting for 0.8 up to 2.6 percentage points. This result is in accord with the results for other countries (cf. Budd / Hobbis, 1989, Budd / Hobbis, 1989a and Coe / Moghadam, 1993). The role of standardisation is in second position, accounting for 0.2 up to 1.5 percentage points of the average annual growth rates. However, coinciding with the reduction of growth of the stock of standards at the beginning of the eighties, the impact of standards on economic growth moves to a lower level.

The impact of the factor labour on economic growth is strongly influenced by cyclical fluctuations of the number of employees. Especially the reductions of the number of employees after the first and second oil price crisis had negative impacts on economic growth. On the other hand, the strong increase of the number of employees in the second half of the eighties has fostered economic growth. The lagged stock of patents and the real licence expenditures had in most cases a moderate influence on growth. Nevertheless, these two sources of technical progress account for slightly more than 18 % of the total increase of gross value added in the period from 1961 until 1990. Their share increases even to 35 % in the second half of the eighties, but only due to the strong increase of real licence expenditures.

Altogether, the results suggest that the sources of technical progress considered here as well as the diffusion of technology contribute substantially to economic growth in Germany.

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Abstract

An aggregate production function for Germany from 1960 until 1996 is estimated. In contrast to most other empirical studies, technical progress is not approximated by a linear time trend but we distinguish between technical progress which is a result of own R&D activities, and the import of technological know-how through licence agreements, approximated by the indicator variables stock of patents and real expenditures for licences. In addition, technology diffusion, as approximated by the stock of effective technical standards, is integrated in the long-term production function. The superior long-term production function, including the usual production factors as well as the three indicator variables, is then used to assess the effects of the different sources of technical progress as well as technology diffusion on economic growth from 1961 until 1996.

Zusammenfassung

In diesem Aufsatz wird eine langfristige Produktionsfunktion für die Bundesrepublik Deutschland von 1960 bis 1996 geschätzt. Im Gegensatz zu anderen empirischen Studien wird dabei der technische Fortschritt nicht durch einen linearen Zeittrend approximiert, sondern es wird zwischen technischem Fortschritt, der das Resultat eigener FuE-Aktivitäten ist, und dem Import von technologischem Know-how durch Lizenzverträge unterschieden. Beide Einflußgrößen werden durch die Indikatorvariablen Patentbestand und reale Lizenzausgaben erfaßt. Zusätzlich wird die Diffusion von Technologien innerhalb einer Volkswirtschaft, die durch den Bestand an technischen Normen approximiert wird, in die langfristige Produktionsfunktion integriert. Die überlegene Produktionsfunktion, die sowohl die üblichen Produktionsfaktoren als auch die drei Indikatorvariablen einbezieht, wird dann verwendet, um den Einfluß der einzelnen Größen auf das Wirtschaftswachstum von 1961 bis 1996 abzuschätzen.

JEL-Klassifikation: E 23, O 30, O 52, C 22, C 52