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The impact of patents and standards on macroeconomic growth: a panel approach covering four countries and 12 sectors

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Abstract Based on the assumption that codified technological know-how contributes to economic growth, this paper presents the estimation of a Cobb–Douglas production function, pooling data from four European countries and 12 sectors. The empirical results confirm that both the stock of patents and the stock of technical standards contribute significantly to economic growth in the 1990s. Whereas the results of the country models are rather similar, we observe significant differences between the sector models, which indicate that standards are more important for growth in less R&D-intensive industries and patents in R&D-intensive industries.

Keywords Growth · Innovation · Standards · Patents · Country effects · Industry effects

JEL Classifications O41 · O52 · O11 · E13

1 Introduction

A rather new aspect which has not been dealt with in depth in economics literature is the role of technical standards for economic growth, although the importance of technological activities as an essential determinant of the economic performance of industrialized economies is generally acknowledged today.[1] In contrast, the role of the patent system in economic growth received greater attention, beginning with Nordhaus (1969) until the recent paper on patents in endogenous growth models by O'Donoghue and Zweimueller (2004), who examine the role of different patent policies in an endogenous growth model developed by Grossman and Helpman (1991), as well as Aghion and Howitt (1992).

Theoretical growth literature does not consider the role of technical standards, but focuses mainly on input indicators in the innovation process, like R&D expenditures or even patents. It is undisputed in the meantime that technical standards are very important for the fast and efficient diffusion of new technologies (Swann 2000), which corresponds very well to knowledge-spill-overs as drivers of growth in the endogenous growth models. However, the diffusion aspect covers only one macroeconomic impact dimension of standards. Furthermore, the standardization process itself is a platform, especially for the exchange of knowledge relevant for the implementation of new technologies among its participants. This dialogue enables the generation of new incremental and more application-related technological know-how instead of radical breakthroughs in basic research. In the following section, we do not concentrate on the aspects of tacit knowledge exchanged and created by the participants in standardization processes, but try to emphasize that the different types

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[1] Standards can also be interpreted as institutions. Institutional economists postulate a close relationship between institutional development and economic growth. Cf. the general survey in Frenkel and Hemmer (1999), who do not consider standards, as well as Glaeser et al. (2004) recently.

of standards according to David's (1987) typology have different impacts on growth (Blind 2004).

All types of technical standards codify technological know-how. Codified technological know-how has a public good character in the sense of non-rivalry in use and can therefore be easily distributed among different companies[2] or the whole industry (Cohendet and Steinmueller 2000). Besides the common dimension of non-rivalry in use, we divide codified knowledge into two subsets distinguished by the degree in which property rights and excludability are attached to them. Whereas innovations protected by intellectual property rights, like patents, restrict others from using the technologies covered, technical standards are in general public goods and a form of technical infrastructure (Tassey 2000). From a theoretical perspective, public infrastructures are able to increase the productivity of the other input factors labour and capital, and from empirical studies (e.g. Schlag 1997) we learned that public infrastructures positively influence economic growth. The faster and greater the diffusion of private technological know-how by technical standards is, the greater also the pool of this publicly available information and the stronger its impact on growth.

Discussing the role of compatibility and interface standards leads us also to the infrastructure argument, because our transport systems, the networks supplying us with water, gas and electricity and, finally, the telecommunication infrastructures, depend crucially on this type of standards. Since all the service sectors based on these physical networks are both the most dynamically growing sectors in highly industrialized countries and also enrich the development in the manufacturing sector (Jungmittag and Welfens 1996), overall growth can be positively influenced by efficient compatibility standards. However, if central compatibility or interface standards are in the ownership of a single company or a small group of companies, their monopolistic behaviour can decrease consumer surplus, inhibit innovation and therefore hamper economic growth in the short and long run.[3]

The category of minimum quality and safety standards is growth-enhancing, because these standards reduce transaction costs, especially with respect to markets for complex and "risky", but also innovative and high quality products and services. Consequently, they have a positive impact on the development of new markets and high quality segments of existing markets. These markets are decisive sources for growth, especially for highly industrialized countries, and their tendency towards saturated markets for durable consumer products. Finally, safety standards are a means to restrict negative externalities damaging health and the environment. The resources saved and not used to fix the damage can be allocated more efficiently, which enhances growth. Negative for growth is the misuse of minimum quality or safety standards by small groups of suppliers, who try to manipulate the specification of these standards in a way that raises their rivals' costs and allows them to behave like monopolists. Furthermore, the restriction of product or service range by this category of standards can be too strong, in the sense that the number of customers with a demand for low quality and low safety products is relatively high, compared to all customers. Thus the loss of their consumer surplus is higher than the gain of consumer surplus for customers with stronger preferences for quality and safety features.

Regarding the previous categories of standards, the growth-enhancing effects dominate the growth-hampering effects. The situation is rather ambivalent for variety-reducing standards. On the one hand, variety reduction allows the exploitation of economies of scale (Dixit and Stiglitz 1977). Furthermore, variety reduction is a necessary condition for the development of new technologies and markets, because a dominant path or trajectory for technologies or market has to be found in order to reach critical masses, which make both an investment attractive for entering companies and use attractive for customers. Both aspects are certainly positive for the growth of the economy as a whole. On the other hand, variety reduction restricts the choices for customers. Following Romer's seminal contribution to endogenous growth models (Romer 1990), Grossman and Helpman (1991) assume in their endogenous growth models that R&D activities aim to reduce either production costs or to extend the product range. In this special framework, growth is equal to the number of product variants. Additionally, Saviotti (1996) postulates that growth in variety is a necessary requirement for long-term development, but also a phenomenon of growing economies.[4] Besides the tension between the exploitation of economies of scale and variety, the reduction of the latter may facilitate the concentration within a market to a smaller number of suppliers, who are able to realize higher economies of scale, on the one hand, and to misuse their market power on the other hand. Weighing all arguments against each other, it remains open whether variety-reducing standards are growth-fostering or growth-hindering.

Finally, we have to consider the important role of standards for trade. Assuming that standards foster trade instead of hampering it, based on the empirical results found by Swann et al. (1996) and Blind and Jungmittag (2005), we can postulate an indirect positive impact on

[2] Benezech et al. (2001) analyse the role of ISO 9000 for knowledge codification within companies.

[3] The most popular example is the case of Microsoft which is accused of misusing its de facto standard on office software.

[4] Funke and Strulik (2000) explain the increasing variety of goods within an endogenous growth model by the output of R&D efforts.

Table 1 Types of standards and their impacts on growth

	Positive impacts	Negative impacts
Compatibility and interface standards	Physical networks based on compatibility standards are the basis for most service industries	Restricted diffusion in case of proprietary standards
Minimum quality and safety standards	Foster development of new markets and high quality segments of existing markets, which are decisive sources for growth	Misuse by small groups of suppliers in order to raise rivals' costs and allows them to behave like monopolists
	Safety standards are means to restrict negative externalities damaging health and the environment	Too restrictive quality and safety standards hinder the development of markets
Variety-reducing standards	Foster the exploitation of economies of scale	Restrict the choices for customers
	A necessary condition for the development of new technologies and markets in order to reach critical masses attractive for entering companies and customers	Foster concentration within a market to a smaller number of suppliers misusing their market power on the other hand

growth. According to Grossman and Helpman (1991), trade is an additional channel for the world-wide diffusion of technological knowledge stimulating innovation and therefore growth. Furthermore, trade of technologies reduces the duplication of R&D effort and consequently increases the productivity of resources employed in the R&D sector, which also enhances growth.

Taking all categories of standards and all economic explanations together (see Table 1), one can derive that standards are likely to be positive for economic growth, especially if the standardization process is open and transparent for all interested groups and the standards themselves are not proprietary, but accessible and usable for all producers and customers.

The empirical economics of standards is only in its infancy.[5] Especially the macro-economic impacts of technical standards have—in contrast to the impacts of patents—not yet been analysed in depth and have not taken all country or sector differences into account. Recently, however, a macro-econometric study of the role of standards was carried out for Germany (Jungmittag et al. 1999). This study suggested that standards were responsible for a significant proportion of the growth in output of the German business sector between 1960 and 1996. For example, in the period from 1960 to 1990 (i.e. prior to reunification), the authors report that standards contributed an estimated 0.9% points to an overall growth rate of output of 3.3% per annum. This was reckoned to be second in importance only to capital accumulation over the whole period—and more important than other sources of technological change, such as domestic innovation and the direct payment for imports of technology from abroad. However, the contribution of the stock of standards decreased to 0.3% within an overall growth of 1.5% per annum after the reunification of Germany. Temple et al. (2004) partly replicated the approach for the United Kingdom and found significant, but smaller contributions of the British stock of standards to growth in the UK between 1948 and 2002.

In order to confirm the results of Jungmittag et al. (1999) for Germany and the partial replication for the UK by Temple at al. (2004), but primarily to allow for sector differences, we apply for the first time a harmonized approach for the four largest economies in the EU, Germany, the United Kingdom, France and Italy. Due to data restrictions, only data for the period between 1990 and 2001 could be used. This restriction was circumvented by setting up a database of sectoral time series, which were pooled in order to generate a sufficient number of observations. In addition, the data of the four countries also allowed a pooling of data by sector, which takes into account the differences of the impact of standards, but also patents, between sectors, although we are not able to differentiate the total stock of standards by their economic functions (Swann 2000). Finally, we tried for the first time to assess the impact of national and supranational standards on economic growth separately.

The remainder of the paper is structured as follows. First, the growth model and its econometric implementation are presented in Sect. 2, which describes also the data used. In Sect. 3, we present the results of the overall model, the country models, the sector models and finally the results of a modified approach which assumes different impacts of national and European or international standards. The paper concludes with a brief summary of the results.

2 The model and the data

This paper applies a simple growth model, which was applied for Germany and the UK, but is modified according

[5] Blind (2004) provides an overview of existing macroeconomic and sectoral studies.

to data restrictions. This adjusted approach will follow and develop the work of Jungmittag et al. (1999), in which estimates of the contribution of standards to growth is based upon a simple neo-classical production function:[6]

$$Y(t) = A(t)[F(K(t), L(t))]. \tag{1}$$

Here, Y is a measure of aggregate value added, A is neutral technological change and K, L are measures of capital and labour input and t is time. The study by Jungmittag et al. (1999) seeks to establish the impact of various sources of technical progress by supposing that A is a function of various forces influencing technological change. If Z(t) is a vector of such influences, we can write:

$$A(t) = A[Z(t)]. \tag{2}$$

They distinguished between technical progress which stems from domestic innovative activity, the import of technology from abroad, and the role of domestic diffusion of technology. They suggest that the three factors can usefully be proxied by domestic patent counts, by payments for technology licenses and by the effective stock of standards. After checking the feasibility of this approach by surveying the availability of the required data, we decided to focus on the four countries UK, Germany, Italy and France, dividing the manufacturing sector into 12 subgroups covering the time horizon between 1990 and 2001. Furthermore, we had to adjust the methodology applied by Jungmittag et al. (1999), since we have no data for payments for foreign licenses. Besides the differentiation into sector-related data, in a second step we are able to differentiate the stock of standards into national, European and other international standards based on searches in the standard database PERINORM edited by the national standardization bodies of France, Germany and the United Kingdom, taking into account the massive influence of European standardization on national standardization activities.[7]

The available data allows us to estimate the following general equations, linear in logarithms (which are denoted by lower case):

$$y_{ij}(t) = a_i + b_j + c_t + \alpha k_{ij}(t) + \beta l_{ij}(t) + \gamma pat_{ij}(t) + \delta totstd_{ij}(t) + u_{ij}(t), \tag{3}$$

$$y_{ij}(t) = a_i + b_j + c_t + \alpha k_{ij}(t) + \beta l_{ij}(t) + \gamma pat_{ij}(t) + \delta natstd_{ij}(t) + \varepsilon eustd_{ij}(t) + \phi intstd_{ij}(t) + u_{ij}(t), \tag{4}$$

where y(t) = real added value at time t (source: OECD STAN), k(t) = real capital stock at time t (source: OECD STAN), l(t) = employment input at time t (source: OECD STAN), pat(t) = indicator of domestic patent stock applied for at the European Patent Office at time t,[8] totstd(t) = effective total stock of standards at time t (source: PERINORM), natstd(t) = effective stock of national standards at time t (source: PERINORM), eustd(t) = effective stock of European standards at time t (source: PERINORM), intstd(t) = effective stock of international standards at time t (source: PERINORM), u(t) = error term, i = country (UK, Germany, France, Italy), j = sector (see Table 2), t = time (1990–2001).

Besides including sector, country and time fixed effects a_i, b_j and c_t in the total model, which will be based on more than 500 observations, it is also possible to estimate the model per country and for selected sectors.

The results of these estimations will generate significant progress in the research on the impact of standards on economic growth, controlling for country, and more important, for sector differences.

3 Results

In the following section, we present the results of the estimations for various versions of the Eqs. 3 and 4. In addition to the traditional ordinary least square regressions, including dummy variables for country, sector and time effect effects, we performed so-called Ridge regressions, since we are confronted with strong multi-collinearity between the independent variables, which makes it difficult, if not impossible, to determine their separate effects on the dependent variable. Neter et al. (1996) define Ridge regression as one of several methods that have been proposed to remedy multi-collinearity problems by modifying the method of least squares to allow biased estimators of the regression coefficients.[9] This method falls into the

[6] Maskus and McDaniel (1999) used a similar approach for Japan, using the following Cobb–Douglas production function.

[7] Since some standard documents (with the exception of German standards) are not classified by the international classification for standards ICS before 1994, we had to adjust the former stocks by a small correction factor in order to avoid too high growth rates.

[8] Based on Schmoch et al. (2003), a series of patent applications at the European Patent Office differentiated by country and the NACE 2-digit classification were available. These data formed the basis for the construction of a patent stock indicator.

[9] The method uses a 'ridge' parameter (r) to produce a set of coefficient estimates from the matrix X of independent variables and the dependent variable y according to $(X'X + rD)^{-1} X'y$. Here D is a diagonal matrix created from the diagonal from X′X and r is a scalar chosen so that small variations produce stable estimates. While this produces a biased estimator, its covariance matrix can be shown to be smaller than that of the ordinary least squares estimator $(X'X)^{-1} X'y$.

Table 2 List of sectors and their NACE codes

1. Food products, beverages and tobacco	15–16
2. Textiles, textile products, leather and footwear	17–19
3. Wood and products of wood and cork	20
4. Pulp, paper, paper products, printing and publishing	21–22
5. Chemical, rubber, plastics and fuel products	23–25
6. Other non-metallic mineral products	26
7. Basic metals and fabricated metal products	27–28
8. Machinery and equipment, n.e.c.	29
9. Electrical and optical equipment	30–33
10. Motor vehicles, trailers and semi-trailers	34
11. Other transport equipment	35
12. Manufacturing n.e.c.	36–37

category of biased estimation techniques; that is, though ordinary least squares give unbiased and minimum variance regression estimates, there is no upper boundary on the variance of the estimators, and when multi-collinearity occurs, it may produce large variances. When the variance is reduced using biased estimation, a noticeable increase in stability occurs in the regression coefficients. Reducing variance may provide benefits that offset any loss suffered due to using biased estimates. An estimator that has only a small bias, and that is substantially more precise, is the preferred estimator because it is more likely to be closest to the true value of the parameter (Myers 1990).

3.1 The total model

We start in Table 3 with the presentation of the results of the total model, which includes all four countries and all 12 sectors. The OLS regressions (LSDV) including dummy variables for country, sector and time effects reveal very significant partial production elasticities for the three input factors capital, labour and the patent stock.[10] Only the coefficient for the total stock of standards fails to be significant. However, the second model, not including time effects due to their insignificance in the first total model, reveals that all four input factors are significant. Nevertheless, the second LSDV model is not satisfactory with respect to the size of the partial production elasticities, because both the partial elasticity of labour and of the patent stock are rather high, and the partial elasticity of the capital stock is rather low. The performance of the Ridge regression explained above yields a slightly more sensible range of partial production elasticities. First, the coefficient for capital is 0.23, which comes closer to the share of one third; second, the coefficient for employment is just below two thirds; and finally, both the patent stock and the stock of patents are significant and in a range which corresponds to Jungmittag et al. (1999) and other studies based on German and OECD data (see below). The partial production elasticity of the patent stock is around 20% higher than the elasticity of the stock of standards. Since country and sector dummies are significant, we will also present and discuss the separate country and sector models, in order to be able to identify more differentiated patterns and respective conclusions.

3.2 The country models

Since we have more than 100 observations for each of the four countries, we have also estimated four separate country models. These separate models are able to take into account national idiosyncrasies, not only of the national standardization system and its impact on macroeconomic performance, but also of the national capital and labour markets and the specific patent system, although the completion of the Single Market and the establishment and success of the European patent system should have led to an increasing convergence between the different national systems. However, current growth, but also employment figures and technology indicators, like patent intensities, confirm that we still have different national economic systems, which cannot only be explained by different sector structures.

Due to high multi-collinearity, the LSDV method also provides rather unrealistic estimates for many of the coefficients of interest for the country models. Thus only the Ridge regression results are shown in Table 4. For comparison, the Ridge regression estimates of the preferred total model are again displayed in the second column of this table. The third column shows the results for the UK. Here, the two partial production elasticities of the patent and the standard stocks are in the same order of 0.05. Furthermore, the partial production elasticity of the factor capital is around one third, which corresponds closely to magnitudes known from other empirical studies (see Harrigan (1999) and below the references for Germany).

For Germany, the Ridge regression generates an estimation equation with four significant and reasonable partial production elasticities.[11] However, the production elasticity of the patent stock is more than three times higher at 0.09 than that of the standard stocks at 0.03. As already indicated in Jungmittag et al. (1999), these results confirm

[10] The inclusion of country, industry, and time effects allows us to capture all kinds of special effects, which also prohibits that these effects are attributed to contributions of the stocks of standards or other input factors.

[11] Smolny (2000) finds for 51 German sectors based on time series between 1960 and 1990 production elasticities for capital between 0.269 und 0.415. On a macroeconomic level, Schröer and Stahlecker (1996) discover production elasticities of 0.666 for labour and 0.353 for capital.

Table 3 Estimation results for all four countries and 12 industries, 1990–2001 (n = 509)

	Model 1 LSDV	Model 2 LSDV	Model 3 Ridge Regression
Capital	0.104 (3.998)[a]	0.118 (4.490)	0.230 (11.639)
Labour	0.801 (33.055)	0.772 (34.583)	0.648 (30.912)
Patent stock	0.270 (5.185)	0.324 (8.841)	0.105 (11.785)
Standards (total)	0.033 (1.526)	0.049 (2.314)	0.079 (6.077)
F-tests			
Country effects	47.990 (0.000)[b]	51.650 (0.000)	Yes
Industry effects	21.447 (0.000)	28.395 (0.000)	Yes
Time effects	1.158 (0.314)	–	
Ridge parameter[c]	–	–	0.015
$R^2_{adj.}$	0.976	0.976	0.965

[a] t-values in brackets, t = 1.645 (or 2.325) for a significance level of 5% (or 1%) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation

[b] Significance levels in brackets

[c] See footnote 11

Table 4 Estimation results (ridge regressions) for the country models, 1990–2001

	Total model	United Kingdom	Germany	France	Italy
Capital	0.230 (11.639)[a]	0.344 (26.767)	0.227 (10.704)	0.518 (12.488)	0.291 (33.989)
Labour	0.648 (30.912)	0.455 (18.235)	0.417 (13.925)	0.302 (5.540)	0.314 (43.750)
Patent stock	0.105 (11.785)	0.047 (9.465)	0.094 (9.095)	0.072 (5.210)	0.059 (32.692)
Standards (total)	0.079 (6.077)	0.052 (4.485)	0.027 (2.666)	0.147 (5.754)	0.017 (3.112)
Country effects	Yes[b]				
Industry effects	Yes	Yes	Yes	Yes	Yes
Time effects		Yes			Yes
Ridge parameter	0.015	0.015	0.015	0.015	0.06
$R^2_{adj.}$	0.965	0.985	0.984	0.955	0.968
NOBS	509	140	132	127	110
Industries	12	12	12	11	10

[a] t-values in brackets, t = 1.645 (or 2.325) for a significance level of 5% (or 1%) (one-sided test)

[b] Only statistically significant fixed effects are included

that the macroeconomic impact of formal standards has lost in importance compared to its higher values in the 1970s and 1980s.

For France, the coefficient of 0.52 for the capital stock and of 0.30 for employment are slightly different from those of the British and the German model, but the partial production elasticity of 0.07 of the patent stocks and 0.15 of the standard stocks are in the same range as in the models presented before. However, the pattern itself is rather diametrical to the situation in Germany, where the patent stock has a partial production elasticity three times higher than the stocks of standards.

In the case of Italy, the successful performance of a Ridge regression required a rather high Ridge parameter of 0.06—four times higher than in the other Ridge regressions. The Ridge model produces partial production elasticities of around 0.30 for the two traditional production factors capital and labour, whereas the partial production elasticity of the patent stocks at 0.06 is more than three times higher than the partial production elasticity of the standard stocks.

To summarize, it is obvious we compare the results of the total model and the country models. If we focus on both the knowledge stock indicators, for the total model we find a slightly higher coefficient for the patent stocks of 0.11 compared to the 0.08 of standard stocks. For the United Kingdom, both are about 0.05 and lower than for the total model. In Germany, the partial production elasticity of the patent stocks is more than three times higher than the partial production elasticity of the standard stocks. The same relationship—but on a level of one half—is found for Italy, whereas in France the partial production elasticity of the standard stocks is 0.15, which is more than double that of the elasticity for the patent stocks.

Altogether, there are rather similar partial production elasticities of the patent and standards stocks in the four countries. However, significant differences with respect to the relation between them can be observed. One explanation for these differences can be different sectoral structures, because the institutional settings both for the standardization and the patent system are rather similar, due to the harmonization efforts at the European level. Therefore, in the next section we will scrutinize the sectoral models.

3.3 The industry models

In addition to separate country models, the data of the four countries allow also the estimation of industry or sector models. From a theoretical perspective, one would expect much more stable results in contrast to the country models, because the differences regarding the interplay between the input factors and their relation to the output between sectors should be much higher than between the same sectors in different countries—and is significant, as confirmed by the significant industry dummies in the various country models. However, the number of available observations for the industry models is rather low and we still observe certain national idiosyncrasies in the same sectors in Europe, despite the efforts to complete the Single Market or to provide similar framework conditions.

Table 5 gives an overview of all the 12 sector models. In the same way as with the country models, the traditional LSDV approaches do not lead to sensible results. Therefore, they are not shown in Table 4. However, even the performance of Ridge regressions only causes significant improvements for some sectors. Although the signs or sizes of the coefficients of the partial production elasticities are not always realistic,[12]we observe a rough pattern regarding the impacts of the stock of patents and the stock of standards. We find mostly significant impacts of the stocks of standards in the sectors, characterized by low and medium R&D and technology intensity, whereas the stocks of patents gain in importance with the increasing R&D intensity of sectors. This very rough structure of a stronger importance of the knowledge base measured by patents in high-tech sectors, and a dominance of standards in low- and medium-tech sectors is reasonable from the economics of innovation and technology, but so far has not been yet been proved, based on sectoral data.

3.4 Models differentiating national and supranational standards

Since the national standardization systems of the four countries are massively influenced by the emerging and expanding European institutions CEN, CENELEC and ETSI and their standardization activities, and also by the international standards developed by ISO and IEC, in a last step we have also analysed the influence of the subsamples of national, European and international standards on the development of real value added in the four countries and 12 industries. We assume that the stock of national standards has a stronger impact on economic growth than the European and international standards, which do not necessarily reflect the preferences of domestic producers or customers, do not exclusively increase the national competitive advantage and may therefore even have negative impacts on national economic growth in some sectors.

Since we observe a substitution of national standardization activities, especially through European standardization, the problem of multi-collinearity becomes even more severe for the regression analyses. Furthermore, we observe a very strong growth of European standards, starting more or less at zero level, which is not reflected at all by economic activities. Finally, there is a close and often coordinated relationship between European and international standardization processes. Based on the theoretical distinction between national standards, on the one hand, and European and international standards on the other hand, and taking into account the special characteristics of the data, we decided to separate the total stock of standards into national and international standards. However, the standards data for Italy did not allow a clear-cut distinction between national and European or international standards. Therefore in the following Table 6 we present the results of the total model, including only the UK, France and Germany. The production elasticity of the national stock of standards reaches a value of 0.12, which is similar to the value of the elasticity of the total stock of standards based on a total model, without relying on Italy. This is consistent, because the elasticity of the European and international standards is close to zero.

The three separate national models of the UK, France and Germany confirm the significant impact of the national stock of standards. However, in contrast to the UK, the stocks of European and international standards also have

[12] However, based on a panel estimation for 11 OECD countries from 1980 to 1989, Harrigan (1999) also finds some low production elasticities for the capital stock and the labour force differentiated by sector: Non-electrical machinery: C: 0.232 L: 0.611; Office and computing equipment: C: 0.209 L: 0.725; Electrical machinery, excl. comm.: C: –0.631 L: 1.258; Radio, TV, and comm. equipment: C: 0.222 L: 0.678; Shipbuilding and repairing: C: 0.422 L: 0.527; Motor vehicles: C: 0.548 L: 0.434; Aircraft: C: 0.189 L: 0.803; Other transport equipment: C: 0.342 L: 0.382.

Table 5 Estimation results for the individual industries, 1990–2001

	Industry 15–16 food products, etc.	Industry 17–19 textiles, etc.	Industry 20 wood products	Industry 21–22 pulp, paper, etc.	Industry 23–25 chemical products, etc.	Industry 26 other non-metallic products	Industry 27–28 metals and metal products	Industry 29 machinery and equipment	Industry 30–33 electrical and optical equipment	Industry 34 motor vehicles etc.	Industry 35 other transport equipment	Industry 36–37 manufacturing n.e.c.
Ridge regression												
Capital	0.110 (4.410)[a]	0.181 (6.763)	0.358 (7.209)	0.197 (7.628)	0.315 (5.394)	0.461 (13.045)	0.314 (6.105)	0.354 (13.152)	0.131 (0.895)	0.846 (6.223)	0.523 (1.708)	0.060 (5.354)
Labour	0.158 (9.057)	0.509 (15.059)	0.353 (6.147)	0.365 (12.168)	0.070 (1.401)	0.179 (4.063)	0.301 (9.906)	0.317 (11.174)	0.528 (4.190)	0.062 (0.744)	0.504 (2.907)	0.122 (3.587)
Patent stock	0.046 (4.211)	–0.063 (–2.685)	0.265 (10.604)	0.075 (6.955)	0.171 (13.137)	0.092 (4.461)	0.132 (9.032)	0.144 (4.801)	0.007 (0.112)	–0.083 (–0.934)	0.243 (3.301)	0.070 (7.420)
Standards (total)	0.043 (4.683)	0.101 (2.380)	0.088 (1.435)	0.013 (0.589)	–0.095 (–2.547)	0.153 (4.738)	0.077 (2.722)	–0.057 (–1.078)	0.052 (0.754)	0.065 (0.348)	0.140 (1.273)	0.110 (5.274)
Ridge parameter	0.1	0.02	0.015	0.015	0.015	0.02	0.015	0.02	0.015	0.015	0.04	0.4
$R^2_{adj.}$	0.931	0.974	0.970	0.990	0.972	0.959	0.985	0.980	0.907	0.954	0.653	0.571
Fixed effects	Country	Country	Country time	Country	Country time	Time	Country time	Country time	Country time	Country time	Country	Country time
NOBS	46	46	34	45	46	46	45	45	45	33	33	45

[a] *t*-values in brackets

Table 6 Estimation results with differentiated standards for all countries without Italy (n = 399)

	Model 1 LSDV	Model 2 LSDV
Capital	0.172 (5.552)	0.180 (5.783)
Labour	0.789 (27.332)	0.782 (27.030)
Patent stock	0.500 (7.451)	0.479 (8.774)
Standards (national)	0.117 (5.373)	0.117 (5.434)
Standards (EU + international)	–0.001 (–0.030)	0.009 (0.481)
F-tests		
Country effects	52.198 (0.000)	74.783 (0.000)
Industry effects	22.376 (0.000)	26.135 (0.000)
Time effects	1.016 (0.432)	–
$R^2_{adj.}$	0.980	0.980

significant production elasticities for the two other countries. The value is rather small in the German model, but for France it reaches a value almost similar to the production elasticity of the national standards.

In summary, the approaches to analyse the impacts of national, European and international standards separately have to be improved in future research in several dimensions. First, the quality of the data should be improved in order to ensure a precise distinction between the three groups of standards. Additional information about the country of origin of European and international standards would be very helpful. Furthermore, hypotheses should be developed as to how the changed division of labour in standardization influences the economic sectors at the national level. Finally, at some time in the future, the transition phase after the initiation and catching-up of the European standardization system should be completed and a new equilibrium between the national and European activities should be reached. Then more stable patterns of the division of work and their respective impacts should be observable.

4 Summary

In summarizing the results of the various approaches, the following general observations must be noted. At first, the total model covering all four countries, and also the four separate country models, confirm the significant influence not only of the patent stock as an important knowledge pool for economic growth, but also of the stock of formal standards. The production elasticity of the patent stock is slightly higher than the value for the stock of standards. The country models reveal for all countries except France higher production elasticities of the stocks of patents compared to the stocks of standards. These results do not contradict the findings of Jungmittag et al. (1999), who observe a decreasing impact of the stocks of standards since the 1980s.

Whereas the total model and the country models generate reasonable results, the sector models are only partly satisfactory. However, in the more mature and less R&D-intensive sectors, we observe higher impacts of the stocks of standards, whereas the knowledge pool measured by patent applications is more relevant for those sectors with high R&D intensity and a stronger use of high technology. This result confirms the requirement to analyse the impacts of standards differentiated by sector, due to the sector-specific functions of standards.

Finally, the institutional change in the European standardization system and its impact on the national activities has to be mentioned. We tried to take into account the different impacts of national, European and international standards. However, the strong expansion of standardization activities and the simultaneous stagnation of national activities generated additional multi-collinearity problems for the regression analyses. However, the total model covering the three countries the UK, France and Germany without Italy, which does not allow a precise distinction between national and supranational standards, reveals a significantly positive production elasticity for the national stock of standards and a very small and insignificant production elasticity for the sum of the stocks of European and international standards. The results for the three separate country models generate also significant positive coefficients for the stocks of national standards. Analyses separating European and international standards resulted in negative production elasticities especially of the—from a zero level—strongly growing European stocks of standards. It has to be noted that a differentiated analysis of the impact of national, European, and international standards on economic growth, at least within a Cobb–Douglas production function, will only be feasible after the completion of the institutional changes of the European standardization system, also based on a more differentiated set of hypotheses.

This paper is a first step towards an internationally comparative analysis of the role of standards and patents as sources of codified technological know-how for economic growth. The results confirm that research faces numerous empirical, but also theoretical challenges in order to explain economic growth in the knowledge economy.

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