

Blind, Knut; Ramel, Florian; Rochell, Charlotte

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The influence of standards and patents on long-term economic growth

Knut Blind^{1,2} · Florian Ramel¹ · Charlotte Rochell¹

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Abstract

Formal standards codify knowledge. Next to patents representing the generation of innovative knowledge, standards can hence be used to proxy the diffusion of innovative knowledge in macroeconomic growth models. Previous work mainly investigates the positive impact of in particular patents, but also standards on economic growth in short term, single country studies. This study is the first to examine the long-term effects of formal standards and patents on economic growth in a panel of eleven EU-15 countries between 1981 and 2014 using panel cointegration techniques. From policy makers' perspective standardization has also gained recently an increasing attention, e.g. in the call for the development of a European standardization strategy in the update of the industrial strategy. Our results show that European and international standards foster growth for the group of countries but that national standards have ambiguous growth effects in the panel. For patents, no significant effect on growth in this group of countries is identified.

Keywords Economic growth · Standards · Patents · European Union · Panel cointegration

JEL Classification O31 · O33 · O34 · O47

1 Introduction

The endowment with capital, labor and technical progress are the main drivers of economic growth according to economic growth theory (Grossman & Helpman, 1994; Romer, 1990). Whereas the first two factors are clearly defined and have been extensively researched both theoretically (building upon Solow, 1956) and empirically (e.g., Mankiw et al., 1992), technical progress is more difficult to grasp. Nonetheless, actors in our economies continuously develop new technical solutions and improve their efficiency and economic scholars agree that these innovative activities are key for long-term

✉ Knut Blind
knut.blind@tu-berlin.de

¹ Chair of Innovation Economics, Technische Universität Berlin, Sekr. H47, Straße des 17. Juni 135, 10623 Berlin, Germany

² Fraunhofer Institute of Systems and Innovation Research, Breslauer Strasse 48, 76139 Karlsruhe, Germany

economic growth (Aghion & Howitt, 2009). This study uses standards and patents as two indicators for the innovative output of economies in order to assess their impact on long-term economic growth.

A great number of studies have shown the positive growth effects of patents (e.g., Akçomak & ter Weel, 2009; Crosby, 2000; Gould & Gruben, 1997; Hasan & Tucci, 2010; Lach, 1995). Regarding standards, less research has been performed despite their growing economic importance, e.g. for the EU Single Market (in't Veld, 2019). Additionally, standards are very important for the diffusion of new technologies (Swann, 2000) and standardization coincides well with knowledge-spillovers, growth drivers in endogenous growth models (Blind & Jungmittag, 2008). More specifically, Link (2021) reveals a positive relationship between calibration tests, which have public good characteristics and are generally based on standards, and aggregate productivity.

The International Organization for Standardization (ISO) states that a standard is a document that includes requirements, specifications, characteristics or guidelines that can ensure that products, services, materials and processes are suitable for their purpose. We focus our research on the long-term economic growth effects of voluntary standards as key component of the 'tripartite standards regime' (TSR) consisting of standards-setting, accreditation, and certification defined by Loconto and Busch (2010). These standards are collaboratively developed by industry experts, companies, governmental departments, academics, trade associations and consumer groups, thus representing a consensus on best practices. Obligatory technical regulations released by the European Commission or national governments are not considered in this study. Instead, we differentiate on the one hand between national standards published by national standardization bodies and, on the other hand, European or international standards published by European or international standardization bodies.

Standardization and standards can promote innovation and help to diffuse them, ensure competition, improve productivity, efficiency and interoperability as well as guaranteeing high safety, health and environmental protection levels. On a macro-level, all these positive impacts of standardization contribute to economic growth (see for example Blind & Jungmittag, 2008; Hogan et al., 2015). Especially in today's interconnected economies in which production takes place in global value chains, standards are an important means of conveying information about the specifications of products and services (Blind et al., 2018). Standards reduce information asymmetries and make it easier for producers to become part of such value chains (Gereffi et al., 2005; Nadvi, 2008). For these reasons, policy makers have recognized standards as an important tool in economic policy (European Commission, 2015; OECD et al., 2014).

The empirical assessment of the impact of standards on long-term economic growth is – in contrast to the impacts of patents – still in its infancy. Only a few time series studies of certain countries have been conducted, which all find positive effects of standards on growth (Blind & Jungmittag, 2008; Blind et al., 2011; CBoC, 2015; Hogan et al., 2015; Jungmittag et al., 1999; Menon, 2018; Miotti, 2009).

For the first time, this study combines the data of eleven EU member states to perform a comprehensive panel data analysis of the long-term growth effects of standards and patents from 1981 to 2014. The countries are all members of the EU-15, the group of the oldest EU member states. Therefore, this set of countries can approximate the growth effects in an economic union, in which continuous efforts have been made to achieve economic convergence and to build a common market for several decades. Among other instruments, the EU uses unified procedures regarding the granting of patents and the publication of standards to achieve this goal. The foundation of the EPO in 1977 and the so-called New

Approach of 1985, which provides for the harmonization of standards and regulations, mark important milestones in this political process.

In order to deal with the panel data, certain econometric techniques are applied. After checking for a cointegration relationship between the variables using the test developed by Pedroni (1999, 2004), several estimators for panel cointegration in nonstationary panels are applied, namely the fully modified OLS (FMOLS) estimator (Pedroni, 2000), the dynamic OLS (DOLS) estimator (Kao & Chiang, 2000) and the pooled mean group (PMG) estimator (Pesaran et al., 1999).

The results show that standards that are harmonized on the European and international level have a positive effect on long-term economic growth. These supranational standards help to connect the European production networks that build the main clusters of global value chains in times of globalization (Baldwin & Lopez-Gonzalez, 2015; Blind et al., 2018) and thus promote economic development. National standards have, however, no significant effect on long-term growth in the sample. The patent stocks show no clear impact on long-term economic growth. One possible explanation, following Sweet and Eterovic (2019), might be that not knowledge creation but knowledge diffusion drives long-term growth. The results are robust across model specifications.

The remainder of the paper is structured as follows: Sect. 2 provides a literature review. Section 3 presents the empirical strategy and data followed by Sect. 4, which describes and discusses the results. Section 5 concludes.

2 Literature review

Standards codify knowledge and have a public good character (they are non-rival in use). They can thus be a knowledge source for innovation activities and an enabler for the diffusion as well as the adoption of new, innovative technologies (Swann, 2000). Also, the standardization process itself includes the exchange and creation of knowledge (Blind & Mangelsdorf, 2016). Standardization levels the playing field, which leads to competition between and within technologies and thus to innovation. Additionally, standards can foster international trade (Swann, 2010). Especially the adoption of international standards helps the export performance of firms through supporting compatibility, reducing trade barriers, lowering transaction costs and signaling quality to customers. Blind and Jungmittag (2008) provide a more detailed description of the growth effects of the different standard types. For a comprehensive overview of the overall economic benefits of standards, see Swann (2000, 2010).

The economic growth effects of standards have to date only been researched in a small number of empirical studies that are summarized in Table 1. Most of the studies apply a time series analysis for a single country in order to assess the long-term growth effects (Blind et al., 2011; CBoC, 2015; Hogan et al., 2015; Jungmittag et al., 1999; Miotti, 2009; Standards Australia, 2012). Only Blind and Jungmittag (2008) perform a panel analysis of four countries. However, due to the limited time span of the panel, only short-term effects are considered.

Jungmittag et al. (1999) were the first to use time series cointegration techniques in order to examine the long-term growth effects of standards. The authors use a time series for Germany from 1960 to 1996 and find the production elasticity of value-added with regard to standards to be 0.06. The contribution of standards to the economic growth rate

Table 1 Literature overview of empirical studies examining growth effects of standards

Study	Country	Time	Dependent variable	Elasticity regarding standards	Remarks
Jungmittag et al. (1999)	Germany	1960–1996	Value-added	0.06	Independent study
Blind and Jungmittag (2008)	France, Germany, Italy, United Kingdom	1990–2001	Value-added	0.08	Independent study
Miotti (2009)	France	1950–2007	Total factor productivity	0.12	Study for AFNOR
Blind et al. (2011)	Germany	1960–2006	Value-added	0.18	Study for DIN
BERL (2011)	New Zealand	1978–2009	Total factor productivity	0.10	Study for Standards council of New Zealand
Standards Australia (2012)	Australia	1982–2010	GDP	0.12	Study for Standards Australia
Hogan et al. (2015)	United Kingdom	1921–2013	Labor productivity	0.11	Study for BSI
CBoC (2015)	Canada	1981–2014	GDP and labor productivity	0.08 (GDP), 0.16 (labor prod.)	Study for SSC
Menon (2018)	Nordic countries*	1976–2016	Labor productivity	0.11	Study for the Nordic standardization bodies

AFNOR: Association Française de Normalisation, French national standardization body; SCC: Standards Council of Canada, Canadian national standardization body; DIN: Deutsches Institut für Normung, German national standardization body; BSI: British Standards, British national standardization body; Nordic countries: Denmark, Finland, Iceland, Norway and Sweden

in different sub-periods ranges from 0.2 to 1.5%. The methodology of this study was subsequently used in similar and modified versions by several other authors.

In the only available panel data analysis, Blind and Jungmittag (2008) use panel data for the UK, Germany, Italy, and France from 1990 to 2001. With value-added as the dependent variable, the authors estimate a short-run elasticity with respect to standards of 0.08. For the first time, the authors also regard national and supranational standards separately. This separation shows an elasticity of value-added with respect to national standards of 0.12 and to supranational standards of close to zero. These outcomes thus stress the importance of the separate assessment of national and supranational standards.

Miotti (2009) uses French time series data from 1950 to 2007 in a study for the French national standardization body AFNOR. The elasticity of the total factor productivity as the dependent variable with regard to standards is 0.12. This translates into a total contribution of standards to the GDP growth rate in France of 23.8% and to the labor productivity growth rate of 27.1%. Stokes et al. (2011) estimate similar elasticities of total factor productivity with respect to standards for New Zealand for the years 1978–2009. In an update of the Jungmittag et al. (1999) study, Blind et al. (2011) assess the growth effects of standards in a study for the German national standardization body (DIN) using a time series from 1960 to 2006. As the dependent variable, the authors use the production value-added. The elasticity with respect to standards is 0.18, yielding an average yearly contribution to economic growth between 0.7 and 0.8%. A study by Standards Australia (2012) uses Australian data from 1982 to 2010 and finds an elasticity of GDP with regard to standards between 0.10 and 0.15. A time series study by Hogan et al. (2015) for the British national standardization body BSI uses British time series data from 1921 to 2013. The authors measure the growth of labor productivity and find the elasticity with regard to standards to be 0.11 or 0.69% of average labor productivity growth per year. Moreover, the authors find the average influence of standards on GDP growth to be 0.7%. This corresponds to a contribution of standards to total GDP growth of 29.4%. In a study for the Standards Council of Canada, CBoC (2015) find the elasticity of labor productivity with regard to standards to be 0.16 using a time series of Canadian economic data from 1981 to 2014. This translates into an average contribution of standards to the GDP growth rate of about 8%. Menon (2018) estimates the growth effects of standards for five Nordic countries from 1976 to 2016. They calculate an elasticity of 10.5% for the stock of standards at the Nordic level with respect to labor productivity as the dependent variable. The results hold when individual country regressions are performed. Then elasticities range between 0.05 (Iceland) and 0.15 (Sweden).

Summing up, all empirical studies show a positive effect of standards on different variables measuring economic growth with the elasticities ranging from 0.06 to 0.18.

A second form of codified output of R&D that allows to measure innovation are patents (Basberg, 1987; Griliches, 1990). In contrast to standards, they are not public domain but describe proprietary technologies. Inventors file patents when they have developed a novel technology to secure the proprietary rights and constitute a temporary monopoly on the market (Hall, 2007; Hall & Harhoff, 2012).

Although it is widely accepted that innovation drives economic growth (e.g., Grossman & Helpman, 1994), it remains uncertain if stronger IP (intellectual property) protection has positive growth effects. On the one hand, IP protection can be an incentive to innovate because it grants the inventor the right to exploit her invention economically for a certain amount of time. On the other hand, motives to patent are broad and go beyond the mere protection of the invention. For example, Blind et al. (2006) show that strategic objectives like blocking competitors or strengthening the bargaining power of the firm/inventor are

important motives to patent. Additionally, it can be argued that patents facilitate the diffusion of technology and thus drive growth. This is because the information disclosed in the patent is published as part of the patent granting procedure, which allows other actors to build on this new knowledge.

There are a number of studies that report the positive growth effects of patents empirically. To introduce just a few: Gould and Gruben (1997) use panel data from 1960 to 1988 to examine the effect of patent protection on GDP per capita growth in 94 countries. The elasticity with regard to patent protection is 0.42, rising to 1.09 in an instrumental variable estimation. Crosby (2000) uses Australian patent applications from 1901 to 1997 to examine their effect on GDP and labor productivity growth. The calculated elasticity for GDP growth is 0.36 and 0.14 for labor productivity growth. Akçomak and ter Weel (2009) use the number of patent applications per capita in a panel of 102 European regions from 1990 to 2002 to measure their effect on GDP per capita growth. The elasticity of patent applications is 0.19 while controlling for social capital, a proxy for the existing knowledge stock, and institutions. Additionally, the study indicates that social capital only indirectly affects growth by spurring innovation. Hasan and Tucci (2010) use the ratio of granted patents to R&D expenses to examine their influence on GDP per capita growth in a panel of 58 countries from 1980 to 2003. They find an overall positive influence with elasticities varying between 0.06 and 1.87 depending on the econometric method used.

Finally, studies on the growth effects of standards regularly use patent data as a control variable. They find elasticities of patents on economic growth of 0.16 (Jungmittag et al., 1999), 0.11 (Blind & Jungmittag, 2008), 0.12 (Miotti, 2009), 0.34 (Blind et al., 2011), 0.03 (Standards Australia, 2012) and 0.05 (Menon, 2018). In summary, empirical research so far finds a positive effect of patents on economic growth. The reported elasticities range from 0.03 to 1.09 and are, for the most part, considerably greater than the elasticities with regard to standards.

3 Empirical analysis

3.1 Empirical strategy

Following the approach by Jungmittag et al. (1999), the growth model is based on a simple Cobb–Douglas production function as follows:

$$Y_{it} = A_i K_{it}^\alpha L_{it}^\beta e^{\lambda t} \quad (1)$$

The single time series model is extended to a panel model so that Y denotes output, K denotes capital, and L denotes labor each in country i at time t . Technical progress is modeled as a time trend in the form $A(t) = A_i e^{\lambda t}$. The superscripts α , β , and λ represent the respective production elasticities. However, as Jungmittag et al. (1999) argue, it is not useful to regard technical progress as a simple time trend. Using a time trend does not allow to distinguish between the different factors that cause technical progress. This approach models technical progress as taking place in a black box. In order to find out more about the factors influencing technical progress, appropriate indicators have to be used that reflect these factors. As known from the theoretical literature, technical progress is driven by innovation. One possible measure for innovation in macroeconomic research is R&D expenses (e.g., Bassanini & Ernst, 2002). R&D expenses are, however, an input-based approach to measure innovation. A large amount of R&D expenses does not necessarily lead to a large

innovative output (Jungmittag et al., 1999). For this reason, an output-based approach to measure innovation is preferred in this study. Output-based measurements aim to quantify the actual amount of innovation that takes place and only consider the innovations that are available to the economy. Only innovative output can have a direct effect on economic growth.

Patent data are a widely used output-based innovation measure due to good data availability of the number of patents that are held in a country in year t (e.g., Hasan & Tucci, 2010). This stock of patents measures the number of inventions for which a patent was granted by a patent office, i.e., the invention was considered novel enough to grant a patent for it. The use of patent counts has been shown to be superior to the use of an input-oriented R&D measure like R&D expenditures when examining economic growth (Lach, 1995; Lanjouw & Schankerman, 2004). Hence, the patent stock of country i in year t is applied as an indicator for technical progress.

We propose the stock of formal standards as a second measure of innovative output. Standards result from advancements in technology and are agreed upon in standardization processes by all involved market actors. Innovation, therefore, triggers the development of a new standard. In contrast to patents, however, the standardized technology is not protected. The standard document is available for a purchase fee to all interested parties. The standards indicator is defined as the stock of standards in country i in year t . The stock of standards comprises all standards that are valid in year t , i.e., all standards from earlier years plus all standards published in year t minus the standards withdrawn in year t .

In an economy, not only innovations by the domestic firms lead to economic growth. Market actors source technologies from each other, i.e., they use innovations of other companies in their own production. When these innovations are protected by patents or other means of IP protection like, e.g., copyrights, royalties and licensing fees have to be paid to be allowed to use the technology. Therefore, we take the amount of expenses for the use of foreign IP in year t as an additional input variable for the national production function. These payments reflect the amount of technology that is imported and contributes to technical progress (Coccia, 2010; Jungmittag et al., 1999).

To be able to estimate Eq. (1), it is transformed into its logarithmic form. Lower case letters indicate the natural logarithm of the variable:

$$y_{it} = a_i + \alpha k_{it} + \beta l_{it} + \lambda t + u_t \quad (2)$$

Replacing the time trend with the patents and standards as indicators for innovation yields

$$y_{it} = a_i + \alpha k_{it} + \beta l_{it} + \lambda_1 std_{it} + \lambda_2 pat_{it} + u_t \quad (3)$$

The patent indicator is denoted by *pat*, the stock of standards is denoted by *std*, a is the intercept, and u is the standard error term. Equation (3) is estimated as a baseline model.

To get a clearer understanding of the influence of standards on economic growth, the standards variable is split up further. In addition to their economic function, standards can be classified with regard to their scope. In general, one can differentiate between national, regional, and international standards (Blind et al., 2018; Swann, 2010). National standards are published by the national standardization bodies. They are mainly drafted by domestic market actors and thus reflect the domestic technological endowment and knowledge. National standards are tailor-made to the domestic economy (Blind, 2004). In addition, there are regional standards. These standards are similarly tailor-made for the endowment and abilities of certain economic regions such as

the EU (Blind et al., 2018). International standardization bodies publish international standards. These reflect the abilities and interests of global market actors (Blind, 2004).

For the estimation, the standards variable is split up into one variable for the stock of national standards, *nstd*, and a second variable that combines the stocks of EU and international standards, *eistd*. This allows us to learn more about the influence of national standards versus supranational standards on economic growth. EU and international standards are merged in one variable because the development of EU standards started slowly in the 1980s and 1990s so that the stocks of EU standards do not reflect the real economy as indicated by the other economic indicators in these years. The development of the stock of international standards, on the other hand, is in line with the economic development. To smooth these differences, the category of supranational standards is built to gain insights into the effects of national versus supranational standards. Besides these methodological reasons, there are further theoretical considerations behind this approach. National standards, on the one hand, are expected to influence growth positively because they exactly reflect the domestic technical progress. EU and international standards, on the other hand, are developed in similar standardization processes with global stakeholders involved. They are not necessarily made for the economic advancement of certain national market actors (Blind & Jungmittag, 2008). Therefore, it is reasonable to oppose national to supranational standards. Incorporating the differentiation of the stocks of standards, the growth equation now looks as follows:

$$y_{it} = a_i + \alpha k_{it} + \beta l_{it} + \lambda_1 nstd_{it} + \lambda_2 eistd_{it} + \lambda_3 pat_{it} + u_i \quad (4)$$

In the last step, we include licensing fees, *lic*, as a control and additional input for the national production function. Equation (5) is the long-term growth equation and in sum reflects the requirement to combine technological and economic indicators:

$$y_{it} = a_i + \alpha k_{it} + \beta l_{it} + \lambda_1 nstd_{it} + \lambda_2 eistd_{it} + \lambda_3 pat_{it} + \lambda_4 lic_{it} + u_i \quad (5)$$

In order to estimate the long-term growth effects in a panel with medium size of N (number of countries) and a large size of T (number of periods), certain econometric techniques need to be applied. ‘Traditional’ panel methods like random or fixed effects estimators can generate spurious results when applied to macroeconomic data sets with $T > N$ instead of the typical micro-panel data with large N and small T . The econometric methods applied need to take nonstationarity of the time series into account, allow slope coefficients to be heterogeneous and deal with endogeneity of the regressors.

To obtain robust results, three different estimators are used: FMOLS, DOLS, and PMG. All of these estimators are able to deal with nonstationary, cointegrated panels, i.e. they calculate individual short-run effects as well as a common cointegrating vector that forces the long-run effects to converge to a steady state. Pedroni (2000) developed the FMOLS estimator that makes adjustments for serial correlation and endogeneity to the OLS estimator. The estimator first modifies the dependent variable using the average long-run covariance matrix to remove the nuisance parameters caused by serial correlation in the time series of the panel. Then a pooled OLS regression is applied to the modified variables. The DOLS estimator (Kao & Chiang, 2000) augments a regular OLS estimation with the lags and leads of the differences of the regressors to deal with endogeneity and serial correlation. Moreover, it allows for individual short-run effects. Finally, the PMG estimator proposed by Pesaran et al. (1999) is used to test the robustness of the results as well as to prevent an omitted variable bias. This estimator allows for the intercepts and error variances to be different between the countries. Whereas the

short-run effects are also allowed to differ across the countries, the long-run effects are restricted to be the same.

3.2 Data

The panel data is available for the years 1981 to 2014 on a yearly basis and for the eleven countries listed in Table 2. As a measure for the output Y , the gross domestic product (GDP) of a country is used. The capital stock K is the Berlemann and Wesselhöft (2017) aggregate capital stock. The authors provide a capital stock indicator that is consistent overall countries and uniformly covers the long-term panel dimension of more than 30 years. The labor force L is the total number of employees in a country.

Following the method applied by Blind and Jungmittag (2008), the yearly patent stock is calculated on the basis of the number of patent grants by the EPO.¹ The initial stock of the year 1981 is

$$pat_{i,1981} = \frac{grantedpatents_{i,1981} * (1 + \gamma_{i,1977-1981})}{\omega + \gamma_{i,1977-1981}},$$

with growth rate $\gamma_{i,1977-1981} = \frac{1}{4} * \ln(grantedpatents_{i,1981} - grantedpatents_{i,1977})$ and depreciation rate $\omega = 0,15$ as proposed by Hall et al. (2005).

The patent stocks of the subsequent years then are

$$pat_{it} = (1 - \omega) * pat_{i,t-1} + grantedpatents_{it}.$$

Figure 1 depicts the development of the stocks of patents in the sample countries over time. In contrast to both the stocks of standards and the expenditures for royalties and licensing fees, the stocks of patents have slowed their upward movement in the early 2000s and have started to decline in the mid-2000s. The development is most prominently visible for German patent owners because they hold by far the most patents, but can still be observed in all other countries of the panel. This hints at a shift away from the importance of patents as a means of codification of innovations.

The data for expenditures for royalties and licensing fees lic comes from the OECD's Main science and technology indicators database, for the stock of standards from the database Perinorm. The standard stock in a given year is the total number of valid standards in a country in year t , i.e., the stock of standards in $t-1$ plus newly published standards in t minus standards withdrawn² in year t . A standard is counted as being European or international when the database entry indicates that it is harmonized on the European or international level. When there is no indication of harmonization, it is counted as being national.

Figures 2 and 3 show the development of the stocks of national and supranational standards of the panel countries. The stocks of national standards follow a mostly stable, horizontal pattern and seem to exhibit a downward sloping movement in the most recent years. Germany has by far the largest stock of national standards with a stock between 13,000 and 20,000, whereas all other countries, led by France, hold a maximum of roughly 10,000

¹ The majority of countries in our sample joined the EPO in 1977 and 1978. Only Spain, Greece and Finland acceded after 1978 (Spain and Greece in 1986 and Finland in 1996). However, we cannot observe an accession affects in the data for these countries (see Fig. 1).

² Standard withdrawals can be interpreted as the depreciation of the stock of standards over time. Standards are withdrawn when they are, for example, no longer used by industry, technically inadequate, or obsolete.

Table 2 Variables and descriptive statistics

Variable	Description	Source	Observations	Mean	Standard deviation	Min	Max
<i>Y</i>	GDP (US dollars, constant prices and PPPs)	OECD Annual National Accounts database	374	1.14e+12	9.90e+11	1.15e+11	3.83e+12
<i>K</i>	Aggregate capital stock	Berlemaun and Wesselhöft (2017)	374	3.32e+12	2.91e+12	4.73e+11	1.14e+13
<i>L</i>	Total number of employees	OECD STAN Rev. 4*	374	1.40e+07	1.17e+07	2,017,700	4.27e+07
<i>Pat</i>	Stock of patents granted at the European Patent Office	OECD Patents statistics	374	11,433.15	18,187.68	10.85	91,706.93
<i>Lic**</i>	Technology balance of payments for the use of IP	OECD Main science & technology indicators	204	7.39e+09	1.04e+10	8.09e+07	5.70e+10
<i>Nstd</i>	Stock of national standards	Perinorm database***	372	6 260.94	4 713.52	2	19 373
<i>Eistd</i>	Stock of European and international standards	Perinorm database***	372	9 852.40	9 900.46	0	55 582

List of countries: Austria, Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Sweden, Spain, United Kingdom

*Except for Germany, source here: Federal Statistical Office (2020) "Inlandsproduktberechnung. Lange Reihen ab 1970" (<https://www.destatis.de/DE/Themen/Wirtschaft/Volkswirtschaftliche-Gesamtrechnungen-Inlandsprodukt/Publikationen/Downloads-Inlandsprodukt-lange-reihen-pdf-2180150.html>)

**France, Greece, Netherlands, Spain, Sweden are excluded because of incomplete time series data

***Except: for Greece directly obtained from the Hellenic Organization for Standardization

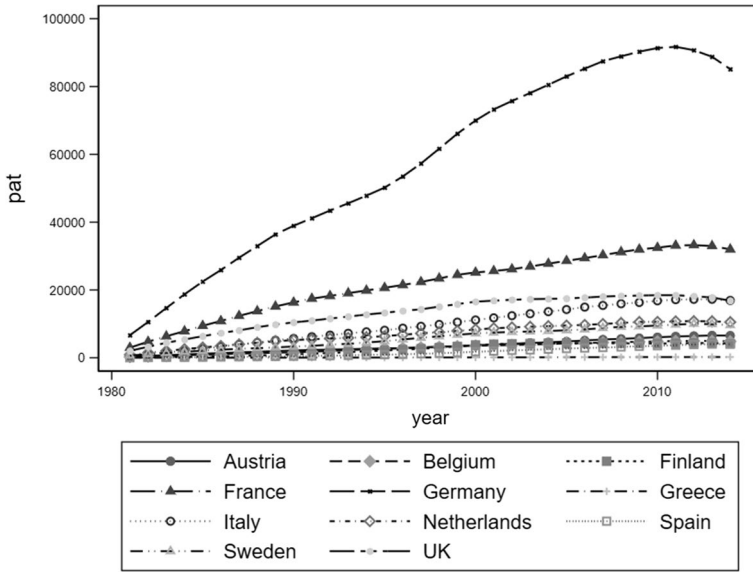


Fig. 1 Patent stocks 1981–2014. (Source: OECD Patent Database)

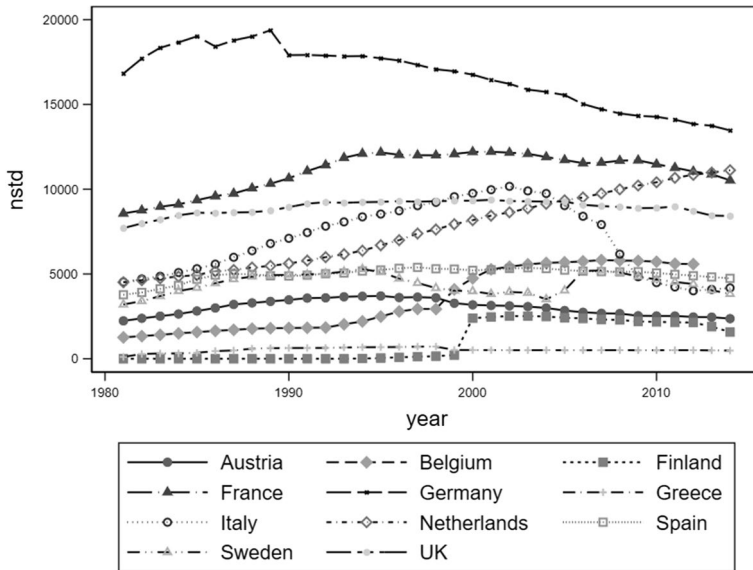


Fig. 2 Stocks of national standards 1981–2014. (Source: PERINORM Database)

at the most. On the contrary, the stocks of supranational standards follow a steep upward sloping pattern since the mid-1990s, with the Netherlands displaying the steepest curve. In summary, supranational standards thus seem to play an increasingly important role while patents and national standards become less popular.

Table 2 provides an overview of all variables and contains some descriptive statistics.

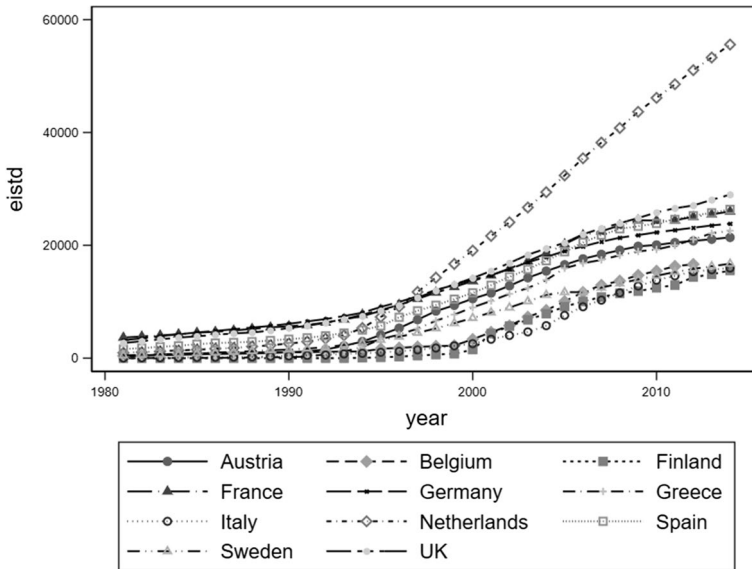


Fig. 3 Stocks of the sum of European and international standards 1981–2014. (Source: PERINORM Database)

4 Results and discussion

4.1 Panel unit root tests

In order to apply the above-presented estimators, the time series need to follow an $I(1)$ process and need to be cointegrated. Only the PMG estimator allows for stationary regressors. Therefore, before testing for a cointegration relationship in the panels, the panel unit root tests by Im et al. (2003) (IPS) and by Levin et al. (2002) (LLC) are applied. Both tests are Augmented Dickey-Fuller (ADF) type tests. The LLC calculates the ADF test statistics on the pooled panel data using OLS. The same autoregressive process across groups is assumed. The IPS takes the average of the ADF test statistics for each group, which allows for each group to have a different autoregressive parameter. This makes the IPS test less restrictive in its assumptions. The null hypothesis of both tests is that all panels contain unit roots; the alternative hypothesis is that some panels are stationary. To take the effects of cross-sectional dependence for both tests into account, the cross-sectional mean from the series is subtracted as suggested by Levin et al. (2002). The tests are performed for each variable in levels and in first differences. Moreover, the tests allow for a different lag order for each panel that is chosen based on the Akaike Information Criterion (AIC).

The panel unit root test results are reported in Table 3. For the test in levels, the unit root null hypothesis cannot be rejected for most variables, and it is then clearly rejected in first differences. It can be concluded that the variables are stationary in first differences and thus follow an $I(1)$ process; they are suitable for cointegration analysis.

Table 3 Panel unit root test results

Variable	Level		First Difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
<i>LLC test</i>				
y	0.4781	-0.9155	-5.7472***	-5.2591***
k	-0.4942	-1.2688	-1.9136**	-1.2629
l	-3.3275***	-0.7047	-7.0682***	-6.4693***
std	-1.0657	1.8346	-12.2010***	-10.4385***
nstd	-0.2344	3.2457	-13.2094***	-11.6088***
eistd	-2.4735***	1.2836	-10.6064***	-9.7006***
pat	-6.8514***	-0.5643	-4.2635***	-4.4166***
lic	-1.5440*	-0.6642	-13.0188***	-10.9355***
<i>IPS test</i>				
Y	0.2356	-0.0236	-5.8016***	-5.0040***
k	0.6898	-2.4840***	-2.3356***	-0.3682
l	-2.1701**	0.3401	-7.1363***	-5.9732***
std	0.1440	0.8297	-11.6618***	-10.1214***
nstd	1.3639	4.2871	-12.7826***	-11.3781***
eistd	0.0174	2.9317	-10.1291***	-8.9040***
pat	-1.5153*	-0.5883	-7.2416***	-7.7117***
lic	-0.7761	-0.8495	-15.0188***	-12.0863***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.2 Cointegration tests

To test for the cointegration relationship, the panel cointegration test developed by Pedroni (1999, 2004) is used. The test allows for heterogeneous dynamics and fixed effects between the countries as well as for differing cointegration vectors across the countries. The null hypothesis is that panels are not cointegrated.

The test computes seven test statistics, which are classified into the two groups within and between dimension statistics (or panel statistics and group-mean statistics). In the former case, the AR parameters are panel specific, and in the latter, they are the same for all panels. The tests allow for a different lag order for each panel, which is chosen on the basis of the AIC.

Table 4 reports Pedroni's cointegration test results for three models: y , l , k plus patents and aggregated standards (model 1—Eq. 3), with patents and differentiating between national and supranational standards (model 2—Eq. 4) and additionally including licensing payments (model 3—Eq. 5). The intercept, as well as the intercept plus trend form of the models, were considered. The tests deliver ambiguous results with some test statistics pointing towards a cointegration relationship and others failing to reject the null hypothesis. Namely, the panel and group modified PP, the modified VR and the group PP tests suggest a long-run relationship between the variables of the three models. We conclude that these results eventually establish cointegration and the FMOLS, DOLS and PMG estimators can be calculated in the next step.

Table 4 Pedroni cointegration test results

Model	(1) std + pat		(2) nstd + eistd + pat		(3) nstd + eistd + pat + lic	
	Intercept	Intercept + trend	Intercept	Intercept + trend	Intercept	Intercept + trend
<i>Between-dimension</i>						
Modified Phillips-Perron	2.154**	2.846***	2.712***	3.128***	2.352***	2.817***
Phillips-Perron	-1.591*	-0.909	-1.507*	-1.457*	-1.687**	-1.204
Augmented Dickey-Fuller	0.601	0.279	0.728	-0.787	-0.904	-0.822
<i>Within-dimensions</i>						
Modified variance ratio	-0.558	-0.956	-1.570*	-1.796**	-1.925**	-2.493***
Modified Phillips-Perron	1.150	1.879**	1.688**	2.105**	1.394*	1.980**
Phillips-Perron	-0.093	0.072	-0.040	-0.654	-1.184	-0.928
Augmented Dickey-Fuller	0.764	0.435	0.698	-0.727	-1.084	-1.161

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.3 FMOLS, DOLS and PMG estimation results

We estimate three models (Eqs. 3–5) to test the long-run influence of standards on economic growth: model one considers the aggregated stock of standards as the independent variable (plus controlling for patents as a well-established proxy for innovation), model two amplifies model one by disaggregating the standard variable into national and supranational standards and model three extends model two by additionally controlling for licensing payments. We apply FOLS and DOLS as two classical long-run estimators for cointegrated panel time series data and the PMG estimator to see whether the results are robust as well as to prevent an omitted variable bias. In a second step, a time trend is included in each estimation to test whether the results hold. Regression results are presented in Table 5.

All three estimators provide evidence of a positive, significant effect of the standard variable. This indicates a positive influence of standards on long-term economic growth and is in line with the findings of previous research. The calculated elasticities vary between 0.02 (DOLS and PMG) and 0.15 (FMOLS). This study prefers the DOLS over FMOLS following Kao and Chiang (2000) who's Monte Carlo simulation suggests that the quality of FMOLS estimator's finite sample properties are lower than the DOLS estimator properties. The estimated coefficients are, therefore, smaller than the elasticities found in the country-specific studies reports (see Sect. 2).

The coefficient for the nstd variable is not statistically significant in the majority of the specifications, i.e., national standards have no clear effect on economic growth in the panel. A look at the descriptive data might explain this result. Only a few countries in the panel hold a strong and large stock of national standards. Hence, the relative unimportance of national standards in the majority of the panel's countries might explain the insignificant effect when regarding the group of eleven countries as a whole. Even though previous research showed that national standards promote economic growth (Blind et al., 2011; Jungmittag et al., 1999), it is also known that these national standards can have negative effects for third countries as they often decrease the openness of the economies and, e.g.,

Table 5 Panel regression results of long-term economic growth effects

	Model 1			Model 2			Model 3								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	FMOLS	FMOLS	DOLS	DOLS	PMG	FMOLS	FMOLS	DOLS	DOLS	PMG	FMOLS	FMOLS	DOLS	DOLS	PMG
k	-0.11*** (5.17)	0.02*** (2.33)	0.51*** (6.76)	0.44*** (3.73)	0.104 (1.59)	0.07*** (19.56)	0.03*** (3.31)	0.52*** (6.44)	0.52*** (6.63)	1.27*** (16.06)	-0.13 (1.64)	0.19 (1.05)	0.64*** (6.55)	0.54*** (3.66)	0.76*** (4.34)
l	0.95*** (47.22)	0.95*** (44.45)	0.55*** (6.65)	0.61*** (8.84)	0.57*** (8.37)	1.03*** (87.08)	0.97*** (84.24)	0.55*** (6.58)	0.55*** (6.79)	-0.21 (-2.27)	0.90*** (44.14)	0.84*** (41.59)	0.49*** (5.96)	0.55*** (7.23)	0.18 (0.85)
std	0.17*** (27.01)	0.15*** (18.17)	0.02*** (3.11)	0.02*** (3.02)	0.02*** (2.80)										
nsid						-0.04*** (13.93)	-0.01*** (18.66)	-0.007 (-0.57)	-0.008 (-1.04)	-0.01 (-1.04)	-0.03*** (4.36)	-0.02*** (5.91)	0.01 (0.59)	0.03*** (3.04)	-0.03 (-1.37)
eistd						0.05*** (12.86)	0.03*** (5.93)	0.02** (2.22)	0.025** (2.74)	0.03*** (3.50)	0.07*** (15.67)	0.07*** (10.81)	0.03*** (3.39)	0.007 (0.81)	0.04** (2.07)
pat	0.08*** (42.03)	0.07*** (32.70)	-0.02** (-2.01)	-0.015 (-1.36)	0.10*** (10.46)	0.08*** (57.78)	0.08*** (37.68)	-0.025* (-1.95)	-0.023* (-1.83)	-0.02 (-0.88)	0.08*** (29.14)	0.08*** (31.09)	-0.11*** (-10.61)	-0.07*** (-6.59)	0.01 (0.38)
lic											0.02*** (8.76)	0.01*** (7.50)	0.03*** (2.71)	-0.002 (-0.23)	0.04* (1.77)
trend	No	Yes	No	Yes	No	No	Yes	No	Yes	No	No	Yes	No	Yes	No

***, ** and * indicate statistical significance at 1%, 5% and 10%

t-statistics in parentheses

Model 1 and 2 are estimated for the full sample, model 3 for a smaller sample (N=6, Austria, Belgium, Finland, Italy, Germany, UK; 1981–2014)

constitute barriers to trade (Blind, 2004; Swann et al., 1996). Thereby national standards make the domestic markets less accessible for foreign firms. This provides a second potential explanation for our results.

European and international standards, on the other hand, have a positive significant effect on long-term economic growth in the panel. By their nature, supranational standards simplify the communication between today's more and more interconnected economies. They reduce information asymmetries, which is increasingly important in today's interconnected global value chains and allows countries to open their economies to international production networks (Gereffi et al., 2005; Nadvi, 2008). This has, e.g., been shown to foster global trade (Swann, 2010). Also, a more international scope of standardization can lead to larger scale and network effects than domestic standards. The national institutions that Zysman (1994) describes as being pivotal for economic development are now, in a much more interconnected economic system, complemented and even sometimes replaced by supranational economic institutions. However, this finding is in contrast to other studies that have distinguished between national and supranational standards. Especially the only panel study by Blind and Jungmittag (2008) find no effect of European and international standards on economic growth. Their research covers, however, only the time frame 1990–2001. As shown in Fig. 3, the greatest rise in stocks of European and international standards has occurred just after that period. The positive growth effects of European and international standards, therefore, seem to be rooted in the developments of roughly the last two decades.

The results for the patent variable are inconsistent and do not indicate a positive effect of patents on long-term economic growth as suggested by literature. Previous studies vary, however, in their econometric approach and scope. Gould and Gruben (1997), Akçomak and ter Weel (2009), Hasan and Tucci (2010), Blind and Jungmittag (2008) as well as Blind et al. (2011), and Lach (1995) apply OLS or instrumental variable methods and can therefore only report the short-run growth effects of patenting. Also, the results might be biased because they do not consider a possible cointegration relationship among the variables. Work by Crosby (2000), Miotti (2009), and Jungmittag et al. (1999) do apply cointegration techniques. However, they are single-country studies and thus, the results are not directly comparable to a panel that comprises eleven countries. This is the first study we are aware of that applies such a methodology to investigate the long-term growth effects of patents while taking a several country, macro perspective.

From a theoretical perspective, patents are directly linked to an invention and thus, new knowledge. A patent is granted for a novel invention and gives temporary monopoly rights to the inventor to protect potential profits. Thus, patents are, as argued above, a widely used innovation indicator in empirical studies, which is facilitated through comprehensive patent databases. However, there are several weaknesses of this indicator revealed by previous research, which might explain our ambiguous results: Not all innovations are eligible for patenting. Also, not all firms choose to protect their inventions through patents and decide to go for alternative IP protection measures. Also, patenting is very sector and firm specific (see Arundel & Kabla, 1998 and Blind et al., 2009 among others). Furthermore, not every invention is an innovation by definition. Following the Oslo Manual (OECD Publishing, 2018), it becomes an innovation when it is “available to potential users” or “brought into use” (p. 20). Research by Giuri et al. (2007) suggests that about a third of patents are not utilized. For those cases, the firm's motivation to patent anyway might, for example, be of a more strategic nature (e.g., blockade of competitors).

More recent work by Sweet and Eterovic (2019) adds to these widely accepted weaknesses and further explains our result. They show for a panel of 70 countries covering

44 years that stronger patent systems do not matter significantly for productivity growth. Based on this finding, they argue that not knowledge creation but knowledge diffusion is the growth driver in increasingly complex production processes. We take up this argument and add that standardization could be an important channel for knowledge diffusion as argued by Blind and Gauch (2009).

Additionally, there is a decline in patent stocks in the later years of the panels. The decreasing importance of patents is thus a possible other factor that helps to explain the absence of a clear long-term growth effect.

The payments for the use of international know-how and services have a clear and statistically significant, positive effect in the majority of specifications. This is in line with the results by Jungmittag et al. (1999) and provides another robustness check for the quality of the data and model. International technology transfer through licensing thus contributes to long-term economic growth because the rights to use this foreign IP are purchased and are then applied in the domestic market. When interpreting this result, it needs to be noted that our *lic* variable does quantify the impact of the foreign IP.

Regarding capital and labor, long-term economic growth is mainly driven by labor and less by capital. In the majority of regressions, the two coefficients add up to one, which is a common result. Overall, the results regarding these two basic variables are in line with the expectations and thus indicate the reliability of the data and the robustness of the estimations.

5 Conclusion

This paper applies a panel cointegration analysis to study the long-term effects of standards and patents on economic growth using a panel of eleven EU countries over the period 1981–2014. It adds a supranational and long-term perspective to previous country-level studies on the growth effects of standardization. The use of three different estimators provides robustness regarding the results. There are, however, specific country-level as well as sectoral characteristics that might influence the overall effects and are not examined individually here. Additionally, the patent and standard variables are simple count variables that do not account for the impact of the patents and standards nor the diffusion of the codified knowledge.

The main findings show that standardization has a significantly positive effect on long-term economic growth, which is in line with previous findings. When distinguishing between national and supranational standards, it is shown that this overall positive growth effect of standardization is driven by the stock of European and international standards in the economies. Those standards possibly trigger economic growth by facilitating the exchange of knowledge in-between the countries as well as between the countries and the world. National standards, however, have no significant effect. Patents seem to have no clear effect on economic growth in the panel supporting new insights by Sweet and Eterovic (2019). Their importance appears to decline when it comes to the codification of innovation.

The following policy recommendations can be drawn from these results. As it becomes clear that national standards have no overarching positive effect for long-term economic growth in core EU countries, policy makers should further invest in a unified and harmonized standardization system in the EU even beyond the New Approach of 1985 in order to make it faster and more efficient (European Commission, 2015). These efforts should

not be limited to the European level. The call for allocating resources towards harmonized standardization systems transfers to the international level as well. Our research provides further evidence that standards are an important tool in economic policy (European Commission, 2015; OECD et al., 2014). Horizon Europe, the predecessor program of Horizon 2020, takes up this suggestion by emphasizing standardization as an instrument for the exploitation and dissemination of research and innovation projects' results (Regulation (EU) 2021/695) and does not only focus on patenting. At the national level, Germany has expanded its program of knowledge transfer via patents and standards to support in particular small and medium-sized companies to participate in international standardization processes since the beginning of 2020. This public funding is justified by the results of our analysis and the findings of Blind and Mangelsdorf (2016) revealing the high importance of participation in standardization as a knowledge sourcing strategy especially for smaller companies. The involvement in international standardization is eventually pushing the effective and efficient implementation of these international standards, to which the domestic companies have contributed to, at the national level.

For policy makers in developing countries, our findings support initiatives designed to promote and invest in the adoption of international standards (Zoo et al., 2017). Their results show that standards facilitate innovation in developing countries by proving quality and by allowing both the exploitation of economies of scale and positive network externalities. They argue that participation in formal standardization is an important avenue of obtaining standards capabilities. However, they observe that developing countries face constraints of technical, organizational, and financial nature in participation in international standardization processes, eventually leading to a lack of their representation in international standards development organizations. Our findings reveal the important role of international standards implemented at the national level. Consequently, developing countries might particularly benefit from supporting their implementation. In the long run, learnings from the implementation of international standards could eventually be an enabler for active participation in international standardization processes.

There are several paths for future research that are worth pursuing. As the service sector is becoming increasingly important and contributes heavily to trade and economic growth (Francois & Hoekman, 2010), services are now regularly standardized (Wakke et al., 2015). Therefore, the specific growth effects of service standards are of interest. Moreover, when the availability of data is given, the panel could be extended to cover all EU-15 countries or any other larger group of countries. Especially the EU is an interesting field of research with regard to long-term effects because one can study the implications of the formation of the economic and monetary union. Also, it would be worthwhile to add some in-depth country time-series studies to the few existing ones, especially for countries outside of Europe (e.g., China). Research on standardization in China is picking up, see, for example, work by Zhang et al. (2020) and Wen et al. (2020) on the effects of standardization on corporate innovation in China. In any case, data availability of time series that are consistent across countries is a challenge. More accurate and longer time-series data will hopefully be available in the future. In addition, the dynamic estimators for nonstationary and cointegrated panels are still relatively new techniques, i.e., there are only a few studies available that apply these methodologies in this context. To get a clearer understanding of the long-term effects of innovation and to check the results of this study for robustness, it would be desirable to see more research of this kind in the future. Finally, linking macroeconomic studies with the insights of the already existing microeconomic studies (Bourke & Roper, 2017; Calza et al., 2019; Wakke et al., 2015) might generate additional insights about the obviously complex and long-lasting impacts of standards.

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