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The economic effects of the quality infrastructure

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ABSTRACT

Although the economic impact of standards has been investigated for over two decades, the effect of the entire quality infrastructure, encompassing standards, conformity assessment, accreditation, metrology, and market surveillance, has been examined primarily through specific case studies. The objective of this analysis is to conduct an econometric analysis to assess the economic value of quality infrastructure on Gross Domestic Product. After a review of the small but growing literature, indicators for the different elements of the quality infrastructure are presented. The panel regression is based on a timeseries of available indicators for a set of European countries. After assessing the impact of each element of the quality infrastructure separately, a comprehensive model is estimated to calculate its total effect. We find that standards are significantly associated with the GDP of the countries, which corroborates earlier studies. Furthermore, the generally good data coverage for ISO 9001 certifications reveals a significant influence of conformity assessment on GDP. Participation in the International Accreditation Forum (IAF) as an indicator for accreditation plays also a substantial role for the country's GDP. However, the approximation of market surveillance by the cases reported in the European Rapid Alert System for Dangerous Products (RAPEX) must be critically assessed due to the ambivalent results. The paper concludes by discussing the overall approach and the revealed results, the limitations and, ultimately, the implied policy recommendations.

1. Introduction

For the economic growth of economies, not only is the input of labor and capital, plus technological progress, essential, but also the quality of the existing institutional and technological infrastructure. Consequently, studies have assessed the role of institutions (e.g., Acemoglu et al., 2001), as well as road infrastructure (e.g., Aschauer, 1989) and IT infrastructure (e.g., Jorgenson & Stiroh, 2000), and have revealed significant contributions to economic growth. However, there is a further type of infrastructure, known as quality infrastructure (QI), which is at the intersection between the country's institutional and technical infrastructure.

The QI is a system comprising various institutions and processes based on standardization, conformity assessment, accreditation, metrology (as per Guasch et al., 2007), and market surveillance (UNIDO, 2018). Furthermore, the UNIDO definition explicitly emphasizes the link between QI and regulation. Within the European Union, the connection between QI and the regulatory framework has been established for over 30 years through approximately 3,500 harmonized European standards. These standards outline the technical details of more general regulations and directives issued by the European Union.

To date, research has primarily focused on the impact of standards alone (see the review by ISO, 2021). However, a comprehensive quantitative impact assessment of the entire QI, which includes standards, conformity assessment, accreditation, metrology, and market surveillance, is lacking. This analysis aims to conduct a preliminary quantitative evaluation of the QI to assess the economic contribution to Gross Domestic Product (GDP) in Europe. Our analysis is, therefore, positioned in the context of SDG 9, Industry, Innovation, and Infrastructure, and SDG 8, Decent Work and Economic Growth, because we investigate for the first time how this specific type of infrastructure is associated with economic growth. Our findings will specify whether QI in total and which of its elements contribute to GDP, and therefore, justify further public policies, particularly investments in QI.

One of the key reasons for the lack of quantitative analyses is also rooted in conceptual ambiguity. Indeed, there have been many

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alternative propositions regarding which key elements the QI encompasses, such as the first publication by Guasch et al. (2007), which later covered market surveillance as proposed by UNIDO (2018). However, our analysis is based on European countries. Therefore, we refer to the definitions provided by the European Commission. First, as the core of the element standardization within QI standards is defined in EU Regulation 1025/2012 as "a technical specification, adopted by a recognized standardization body, for repeated or continuous application, with which compliance is not compulsory". CEN, the European Committee for Standardization; CENELEC, the European Committee for Electrotechnical Standardization; and ETSI, the European Telecommunications Standards Institute, are listed as European standardization organizations, as well as the member organizations of CEN, which serve as national standardization bodies. As defined by the European Commission in the Blue Guide [1], "Conformity assessment is the process carried out by the manufacturer of demonstrating whether specified requirements relating to a product have been fulfilled." As an example of the link between standards and conformity assessment it is stated that "a quality system implemented based on the EN ISO 9000, EN ISO 9001 gives a presumption of conformity with the respective modules about the provisions in the modules that these standards cover".

According to EC regulation 765/2008, accreditation shall mean "an attestation by a national accreditation body that a conformity assessment body meets the requirements set by harmonized standards and, where applicable, any additional requirements including those set out in relevant sectoral schemes, to carry out a specific conformity assessment activity". In the same regulation, market surveillance is defined as "the activities carried out and measures taken by public authorities to ensure that products comply with the requirements set out in the relevant Community harmonization legislation and do not endanger health, safety or any other aspect of public interest protection". This is similar to its definition in the follow-up EC regulation 2019/1020 defining market surveillance as "the activities carried out and measures taken by market surveillance authorities to ensure that products comply with the requirements set out in the applicable Union harmonization legislation and to ensure protection of the public interest covered by that legislation".

In contrast, metrology is neither defined in a specific EU regulation nor in the New Legislative Framework nor in the Blue Guide.[1] However, the EC regulation 2014/32 about the market of measuring instruments, defines metrology in the context of the QI as legal metrological control, specifically as "the control of the measurement tasks intended for the field of application of a measuring instrument, for reasons of public interest, public health, public safety, public order, protection of the environment, levying of taxes and duties, protection of the consumers and fair trading".

While numerous theoretical and empirical studies have been conducted, particularly in the area of standardization, research on conformity assessment has primarily focused on the certification of international management system standards. In contrast, there is almost no research on the diverse effects of accreditation, metrology, and market surveillance. However, the QI has significant implications for overall economic development, considering numerous studies on the benefits of standardization as a core element of QI over the last 20 years (ISO, 2021). Conformity assessment, in particular certification, should also be mentioned here (Manders et al., 2016). Metrology also plays a crucial role, particularly in the areas of research and development (Swann, 2009), and ultimately, for overall economic productivity (Link, 2021). The important non-economic impact dimensions of QI were also addressed quantitatively in the case studies (Wiegmann et al., 2023) and on a much smaller scale with a focus on the role of certifications, e.g., about environmental protection (Arocena et al., 2021; Prakash & Potoski, 2014) or safety (Lim & Prakash, 2017). Finally, the OECD (2022) has dedicated a separate chapter to QI in its analysis of the German innovation system.

In summary, it remains clear that comprehensive quantitative impact assessments related to QI are lacking. Despite the conceptual ambiguities in defining the QI and the resulting difficulties in collecting appropriate indicators, this study aims to provide a preliminary analysis of the economic effects of the QI. However, it will necessarily remain exploratory to some extent, not least because the QI has coevolved with the local economies and other elements of the specific institutional frameworks, which makes causal identification a difficult task. In this respect, our results should be interpreted as being indicative of the economic significance of the QI.

2. Methodology

Against the backdrop of limited knowledge about the role of the QI, we aim to contribute to both theory development and the gathering of empirical evidence on the crucial importance of the QI for the economy. First, we begin with a literature review of the emerging literature on QI. While still a nascent field of science, this step enables us to systematically assess existing works, highlighting what is already known and identifying pertinent gaps. A key aspect is to delineate the relevant QI-dimensions. Second, we use the literature review to develop a testable impact model of all QI-dimensions and how they relate to economic output, as well as science and innovation in general. This impact model, of course, will represent merely a proposition and is up to refinement or revision as more knowledge on the QI becomes available. Third, we use the impact model to define suitable proxies and indicators and collect the data in an integrated database. Fourth, we relate the theoretical impact model to an econometric estimation model, which we then use to estimate the effects of the various QI-dimensions on GDP. It should be noted that the econometric model is consistent with the impact model; however, it is a simplification, as many of the theoretically well-grounded but detailed relationships are not easily estimated within a single overarching econometric model. Thus, the goal of the empirical estimation remains firmly rooted in testing the economic effects of the QI rather than testing the impact model in its entirety. The overall approach is summarized in Fig. 1.

The relevance of our study results from the fact that the findings will enable us to derive concrete policy recommendations, which will help policymakers to adjust the institutional framework or prioritize investments to promote economic development, benefiting society at large by creating jobs or increasing tax revenues to be spent on socially beneficial projects or for less wealthy societal groups.

3. Literature review and the impact model

3.1. Literature review

As the study's starting point is to measure the economic effects of the QI, we conducted a basic systematic literature search using the search term "quality infrastructure" in the title, abstract, and keywords in the Scopus or Web of Science database to identify published articles on the topic. This term was used deliberately, as this study is concerned with the impact of the QI as a whole, rather than the effects of individual components, such as standards. Overview articles already exist in this area, for example, ISO (2021), whose findings are utilized in the development and empirical implementation of the impact model.

The search was completed in September 2025 and resulted in 628 articles in Scopus and 566 articles in the Web of Science, the latter of which were almost entirely covered by the Scopus search. The publications identified by Google Scholar were also briefly reviewed, but this did not yield any additional value. After reviewing the titles and abstracts, 192 relevant articles were selected for analysis. In particular, we excluded numerous articles relating to quality infrastructure in the sense

[1] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C:2022:247:TOC.

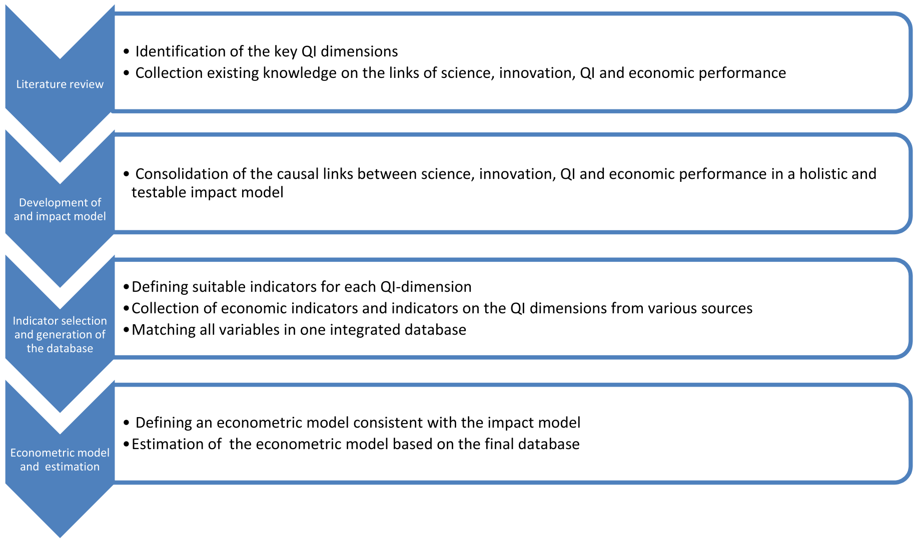

Fig. 1. Overview of the methodology.

of physical transportation infrastructure or quality management, especially in the healthcare sector. A time series shows that the number of published articles has increased significantly from a very low level in the last decade. Yet, despite the growth the literature remains still limited.

In a second step, we mapped the studied countries, which is relevant for our investigation, as the institutional circumstances characterize the national quality infrastructure. China receives the most attention, while the United States of America is not mentioned once. With the exception of Germany, in Europe, Eastern European countries are analyzed more frequently than Western European countries.

In a further step, we assigned the articles to the elements of the quality infrastructure. Almost two thirds of the articles deal with the quality infrastructure as a whole. Surprisingly, nearly a quarter of the articles focus on metrology. The far more prominent topic of standards, on the other hand, is almost not explicitly addressed at all in the articles identified via the term' quality infrastructure,' but is mentioned at most implicitly in the core of the articles. The other cross-cutting topic, regulation, on the other hand, is primarily addressed in the articles on the quality infrastructure. Finally, market surveillance was mentioned only six times. In contrast, regulation was frequently referred to as a framework condition for the national quality infrastructure, but not as an independent element.

In the final step, we reviewed the articles in each category and assigned them qualitatively to different topics. In the case of articles on quality infrastructure, we note, on the one hand, that they refer to specific countries or sectors. On the other hand, they address the impact dimensions of quality infrastructure, particularly in terms of economic and regional development, trade, and foreign direct investment. Almost exceptionally, these are descriptions of quality infrastructure and its potential impact, typically supported by qualitative examples alone.

The few specific contributions on standards within articles on quality infrastructures generally consider them as indicators for benchmarking or roadmaps. The articles on conformity assessment focus primarily on the impact on economic performance in specific countries or sectors. The studies on accreditation also concentrate on either countries or sectors. Finally, articles on metrology often cover several countries. It must be emphasized that half of them consider digital topics, share which has increased in the last few years. Other energy-related articles deal with smart meters and solar cells.

In a final step, the methodological approaches used in the articles focusing on quality infrastructure were examined. In principle, almost all publications are characterized by the fact that they describe the system of quality infrastructure and its institutions in general or primarily in a national context. However, they are also in a global context in a few cases. These descriptions are combined with one or more methodological approaches. The most common analysis method in a quarter of the studies is qualitative case studies, which relate to specific technologies and sectors. Expert interviews sometimes complement these, but are usually limited to very brief surveys. Indicators for the various elements of the quality infrastructure are developed and presented in only ten percent of the studies. Consequently, mainly only descriptive statistics are compiled. Statistical or econometric analyses are typically not conducted. In contrast, political science analyses are often based on descriptions of the national quality infrastructure and its components.

Overall, the literature review on quality infrastructure has revealed that the research landscape is underdeveloped, particularly from conceptual, data, and methodological perspectives. Yet, the literature corroborates the key aspect that relevant QI-dimensions center around standards, metrology, conformity assessment, accreditation and market surveillance. Thus, they should be considered within the development of an impact model of the QI.

3.2. Impact model

While various descriptions of the QI, its components, and their interaction have already been published, there is still no comprehensive impact model of QI.[2] Based on existing impact models for standards (e.g., European Commission, 2022; Swann, 2010), which include both economic and other impact dimensions, such as environmental, health and safety, the findings of these models are initially integrated and updated to include other dimensions, such as sustainability and digitalization. As standards can also be regarded as the basis or core of the QI, further impact dimensions are successively added or existing ones are modified. For example, certificates can increase the impact of standards (Mirtsch, Blind, Koch, & Dudek, 2021a, 2021b), just as accreditation can increase the effects of certificates (e.g., Blind et al., 2018).

The core element of the QI is the standards, which can be differentiated into national, European, and international standards. In their role as a source of knowledge, a prerequisite for interoperability, assurance of quality, and reduction of excessive diversity (Swann, 2010), they have a significant impact on the productivity and, consequently, the

[2] Rab and Brown (2023) present initial thoughts on this but do not present a model.

competitiveness of companies, as well as their ability to innovate. They also support health, safety, and the environment, contributing to the achievement of the SDGs (Blind, 2024; Wiegmann et al., 2023).

Metrology is partly represented by standards, so it has functions similar to the standards themselves. However, in addition to the positive productivity and cost reduction effects, Swann (2009) also identifies beneficial implications for transaction costs and, thus, for creating new markets. Concerning research and development, as well as innovation, metrology plays a crucial role because new scientific findings often require new or adapted measurement approaches. This is a key insight, as Blind (2024) have already demonstrated in their differentiation of the functions of different types of standardization for the phases of the research and innovation cycle. Metrology has economic implications similar to those of standards, but does not necessarily reinforce their functions.

Conformity assessment is typically based on standards, which increases transparency (e.g., Rab & Brown, 2023) of product and process characteristics, thereby reducing information asymmetries between market participants. According to Boiral and Roy (2007), customers, in particular, demand certification as a form of conformity assessment, such as the quality management standard ISO 9001. In addition to these external market-driven reasons, there are also internal benefits, such as the improvement of processes, which in turn enhances productivity and product quality (Boiral & Roy, 2007). However, these advantages must also be considered alongside higher bureaucratic costs, a lack of employee support, and credibility in the audit process (Gyani, 2008). The limiting effect of conformity assessment processes is particularly emphasized for innovations, as noted in the literature review by Manders et al. (2016), especially for radical innovations (Clougherty & Grajek, 2023) or, more recently, for ISO 14001 (Valero-Gil et al., 2023). The conformity assessment of newer management system standards, such as ISO 27001 on IT security, has similar positive effects (Mirtsch et al., 2021a, 2021b) regarding market access and signaling, as well as the character of so-called preventive innovation, analogous to vaccinations. Overall, therefore, both the positive effects of all management system standards and the negative aspects, such as higher bureaucratic effort, insufficient expertise, and critical reactions among employees, are similar. In overall economic terms, significant contributions are attributed to conformity assessment.[3]

While there is extensive literature on the effects of conformity assessment, this does not apply to accreditation (see a recent review by Ramkissoon & Nisi, 2024). Accreditation of conformity assessment bodies enhances their credibility with companies (Blind & Mangelsdorf, 2017) and, consequently, the quality signaling effect of their awarded certificates (Hudson and Jones, 2003). Unreliable certification processes can result in economic losses for certified companies and industries, as investments in quality certifications often fail to yield a positive return or reduce transaction costs. The reliability and independence of certification bodies can be ensured through accreditation, which is based on a set of standards.[4] Overall, accreditation aims to strengthen confidence in quality infrastructure institutions by assessing the competence of organizations performing conformity assessments. It does not complement but instead reinforces the effects of conformity assessment and, ultimately, of standardization. This has been demonstrated by Blind et al. (2018) in relation to trade flows, particularly between developing countries. The recent review of the few macroeconomic studies by Ramkissoon and Nisi (2024) supports the significant effect of accreditation on the economies of New Zealand, Australia, Italy, and the United Kingdom. Estimates of the overall economic significance of accreditation, in particular, were also made for Germany (Technopolis & DIN, 2013). Ultimately, only a leverage effect of over one hundred was assumed in comparison to the turnover of the conformity assessment sector, which includes the German accreditation body. However, no contribution to the overall economy was calculated.

Market surveillance refers to objective and impartial control by national market surveillance authorities after products have been placed on the market. Conformity assessment and market surveillance are complementary and equally necessary to ensure the protection of public interests and the proper functioning of the internal market (e.g., Che & Niu, 2022). According to Regulation (EC) No 765/2008, national market surveillance authorities in the European Union are obliged to proactively monitor products made available on the market throughout their life cycle after being placed on the market to coordinate at the national level and cooperate at the EU level. This regulation is now supplemented by the Regulation on Market Surveillance and Conformity of Products (EU) 2019/1020. Ultimately, the national market surveillance authorities are authorized to impose sanctions ranging up to the destruction of products. The purpose of market surveillance is to ensure that products comply with the applicable health, consumer, and environmental protection requirements throughout the internal market and to prevent unfair competition. At the same time, the aim is to ensure that the free movement of goods is not disproportionately restricted. While studies exist on the incidence of placing dangerous products on the market (e.g., Klaschka, 2017), there are no studies examining the economic and other effects of market surveillance.

Fig. 2 shows the various components of QI and their impact dimensions along the product cycle. The standardization process gives rise to various standards, which can also be initiated within the European Union via mandates.[5] Metrology is based directly on research results or standards. Both components serve as a source of knowledge, support interoperability, ensure quality, and reduce diversity, providing a basis for successful innovations. Once products are ready for the market and have been produced, their conformity with existing standards can be verified. As mentioned above, management processes, such as those for quality assurance and personnel, can also be certified. Overall, the conformity assessment encompasses not only the output but also the input and the company's processes themselves. Accreditation enhances the impact of conformity assessment and, consequently, the role of standards. Once products have been placed on the market, market surveillance, in addition to standards and conformity assessment, ensures that products that violate health, safety, consumer, and environmental protection as defined by harmonized standards and legal requirements are removed from the market.

4. Measurement and econometric approach

4.1. Measuring the QI

In order to map the economic impact dimensions of the QI, the corresponding indicators must be identified and defined for the individual components and their data availability checked. All this information then flows into the empirical analysis. Various data sources are used to carry out a comprehensive impact measurement of the QI with its various elements. In general, research on the QI faces the challenge that, in addition to the lack of an overall conceptual model, data

[3] For Austria, see the study published by the Federal Ministry of Economy, Family and Youth (BMWFJ) on the economic significance of accreditation for the Austrian economy, which, contrary to the title, quantifies the contribution of accredited conformity assessment to the overall economy. Technopolis & DIN (2013) refer to this for Germany and, analogous to the Austrian study, assume similar leverage effects based on the turnover of the conformity assessment industry.

[4] These include ISO/IEC 17020 for inspection bodies, ISO/IEC 17025 for testing laboratories and calibration laboratories, and ISO/IEC 17065 for product certification bodies.

[5] Regulations and legislation ultimately also influence the placing of products on the market. However, production processes are not considered further below because they are not classified as QI in the narrower sense of the term.

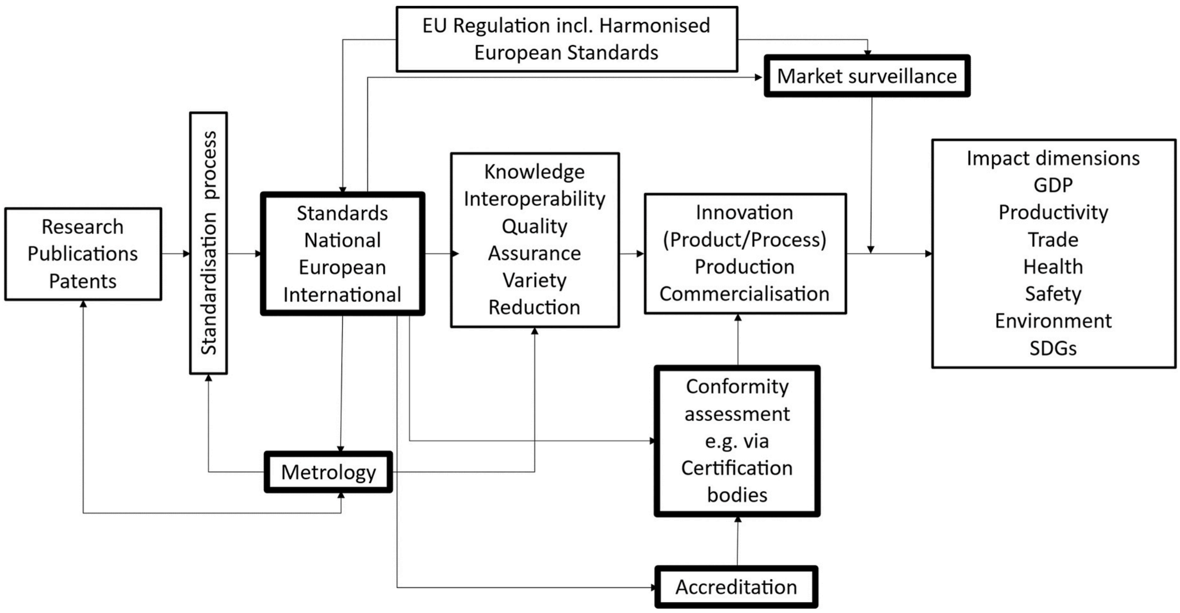

Fig. 2. Impact model of the QI.

availability is limited (e.g. Harmes-Liedtke & Ramkissoon, 2024), and certain impact dimensions of the QI cannot be directly measured with available data.

4.1.1. Standardization

Again, based on standards as the central element of the QI, proven approaches are used here, as they have been implemented in numerous countries over the last two decades (see the overview in ISO, 2021 or currently for the EU (European Commission, 2022). As a rule, the standards valid in a country from 1990 to 2020 are used.[6] The data was taken from the NAUTOS database, the successor to PERINORM.[7] However, we differentiate between national, European and international standards (Blind et al., 2018, 2022a). Finally, the standards relating to metrology are also shown separately (see also below under Metrology). [8]

4.1.2. Conformity assessment

In principle, there are several options for measuring conformity assessment. However, only for the certification of international management standards is corresponding data available at country level from ISO by means of an annual survey of national accreditation bodies.[9] We use the number of company certifications according to ISO 9001, because this is the basic management system standard on which other management system standards are based (e.g., Mirtsch et al., 2021a, 2021b).

4.1.3. Accreditation

In principle, accreditation can be recorded by the number of accredited conformity bodies for product certification, management systems and test laboratories (see also Harmes-Liedtke and Oteiza Di Matteo, 2021; Harmes-Liedtke et al., 2024). However, this information is not available as a time series. In order to operationalize the effects of accreditation in the country panel, we use a dummy variable analogous to Blind et al. (2018), which equals one if the country has an internationally recognized accreditation body, i.e. the national accreditation body is a signatory to the multilateral agreement of the globally operating accreditation organizations International Accreditation Forum (IAF). [10]

4.1.4. Metrology

With regard to the impact dimensions of metrology, there are only a few studies available, mainly due to the limited availability of data. According to Kellermann (2019), a distinction is made firstly between scientific metrology, which includes the definition of units of measurement, the development of new measurement procedures, the realization of measurement standards, the transfer of traceability from standards to users and the definition and maintenance of national measurement standards. Secondly, legal metrology deals with the activities arising from the legal requirements relating to units of measurement, measuring instruments and measurement procedures. Finally, industrial metrology deals with the application of measurements in processes and ensures that measuring instruments are suitable, calibrated and checked for quality.

Consequently, different indicator approaches must also be used with regard to metrology. Scientific metrology is therefore represented by the standards relevant to metrology (see also standards above).[11] As an alternative to standards, metrology patents (transnational applications, see Frietsch & Schmoch, 2010) are also used as an indicator for scientific metrology (Temple & Williams, 2002).[12] Industrial metrology can be measured by the number of calibration laboratories. However, this information cannot be used, because the data is not available, or the timeseries of available data is too short for most of the countries covered. As legal metrology forms the legal basis, a separate indicator is not used here.

[6] The following countries are generally included in the country panel: Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Great Britain, Greece, Hungary, Ireland, Italy, Croatia, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden. However, NAUTOS only records the standards for 16 countries.

[7] See https://www.beuth.de/de/normen-management/nautos.

[8] Here we refer to International Classification of Standards (ICS) 17 Metrology, Metrology, Applied Physics.

[9] See https://www.iso.org/the-iso-survey.html.

[10] Information about the signatories of the IAF MLA can be found on the IAF homepage (www.iaf.nu).

[11] See also Choudhary et al. (2013).

[12] The WIPO35 patent classification (Schmoch, 2008) field 10 (Measurement) is used here.

4.1.5. Market surveillance

Finally, with regard to market surveillance, the information from the annual reports of the European Rapid Alert System for Dangerous Products (RAPEX) is used, as no other quantitative information on market surveillance is available (see also European Commission, 2022). The incidents reported in RAPEX are not an optimal indicator. More appropriate would probably be the resources, such as employees, who are active in market surveillance. However, this information is not publicly available.[13] Therefore, the information from RAPEX is used to complete the indicator set for the QI.

Table 1 lists the indicators used to measure the various components of QI and their sources, while Table 2 lists the economic indicators and their sources. The tables also introduce the formulaic symbols that we will use in the following description of the estimation equations in the next subsection.

4.2. Econometric approach

4.2.1. The economic estimation model

Based on the impact model of Section 3.2 and the available indicators for the individual components, we now derive concrete econometric estimation models, which allow us to estimate the economic effects of the QI. Following the approach of Jungmittag et al. (1999), which has been replicated in numerous studies (cf. ISO, 2021) and further developed (Blind, Ramel, & Rochell, 2022; Blind & Jungmittag, 2008), the basic model is based on a simple Cobb-Douglas production function:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} e^{\lambda t} \tag{1}$$

In the time series model, Y is the gross domestic product GDP or gross value added, K is capital and L is labor at time t in each case. Technical progress is modeled as a time trend in the form $A(t) = A_0 e^{\lambda t}$. In the Cobb-Douglas-model, the exponents α, β and λ can be interpreted as the respective production elasticities.[14] Again following Jungmittag et al. (1999), technical progress is represented by various indicators. One measure of innovation in macroeconomic research is R&D expenditure, which is an input-based approach. However, it does not necessarily lead to innovative output, which is why a more output, strictly speaking, throughput-based measurement approach based on patents is also used (see also Blind & Schubert, 2024). Furthermore, it is not only innovations by domestic companies that contribute to technological progress in an economy. This is because they also use technologies and innovations from other companies and research institutions based abroad. License expenditure for foreign intellectual property can be used as an indicator for this.

Table 1
QI indicators and sources.

Indicators	QI-dimension	Source	Formulaic symbol
Stock international standards issued	Standards	NAUTOS	ino
Stock European standards issued	Standards	NAUTOS	eno
Stock national standards issued	Standards	NAUTOS	nno
Total stock standards issued	Standards	NAUTOS	sumno
Stock international ICS 17 standards issued	Metrology	NAUTOS	inmetno
Stock European ICS 17 standards issued	Metrology	NAUTOS	emetno
Stock national ICS 17 standards issued	Metrology	NAUTOS	nmetno
Total stock ICS 17 standards issued	Metrology	NAUTOS	summetno
Number of ISO 9001 certificates	Conformity assessment	ISO Survey	ISO9001zert
IAF Membership	Accreditation	IAF Homepage	IAFmemb
Number of market surveillance notifications	Market surveillance	RAPEX	RAPEX

Table 2
Economic indicators and sources.

Indicators	Source	Formulaic symbol (logarithmic)
Number of transnational patent filings (inventor country)	PATSTAT	pat
R&D (Research and development expenditure (% of GDP) *Population, total)	World Bank (WDI)	rd
Charges for the use of intellectual property, payments (BoP, current US$)	World Bank (WDI)	lic
Private capital stock (constant 2015 US$)/Net capital stock (constant 2015 US$)	International Monetary Fund (IMF) & OECD STAN	k
Population, total (country model only)	World Bank (WDI)	l
GDP (constant 2015 US$) (GDP)	World Bank (WDI)	y

First, the stock of standards with their impact dimensions is a key factor for measuring the economic impact of QI. Since - in contrast to patents - the knowledge specified in standards is generally not protected, they represent a publicly available pool of knowledge that can theoretically be used by all companies, but also by other organizations.

To estimate equation (1), it is converted into its logarithmic form. Lower case letters denote the natural logarithm of the variables, including α as the intercept value and u as the standard error term:

$$y_t = \alpha_0 + \alpha k_t + \beta l_t + \lambda t + u_t \tag{2}$$

If the time trend is replaced by the three indicators R&D expenditure, patents, license payments and a vector, qi, denoting a varying set of QI indicators, we obtain a generic form of the estimation equation:

$$y_t = \alpha_0 + \alpha k_t + \beta l_t + \lambda_1 rd_{t-1} + \lambda_2 pat_t + \lambda_3 lic_t + \lambda_4 qi_t + u_t \tag{3}$$

To estimate this model, we will rely on a country-level, which is based on the data from the countries listed in footnote 5 for the period from 1990 to 2020,[15] where the panel-equivalent of Eq. (3) is summarized as follows:

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 qi_{it} + u_{it} \tag{4}$$

In the following, we will briefly discuss the specific instantiations of Eq. (4), in which we replace the generic vector qi with specific QI-indicators.

4.2.1.1. Standards. We start our exposition with standards, where we first include the total stock of standards, *sumno*, leading to Eq. (5).

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 sumno_{it} + u_{it} \tag{5}$$

[13] Technopolis & DIN (2013) report on six employees in the central office of the federal states for safety technology and criticize the under-equipment in market surveillance.

[14] The production elasticity is the percentage change in the output quantity for a change in the input quantity of a production factor by an infinitesimally small percentage. It therefore approximates the percentage change in output for an input increase of 1 percent.

[15] For some indicators, the existing time series are also shorter.

In addition, standards can also be classified according to their regional scope. In general, a distinction can be made between national, regional and international standards. National standards are primarily developed by domestic market participants and therefore reflect domestic technological knowledge. They are tailored to the domestic economy. In addition, there are regional standards that are tailored to the preferences of certain economic regions, such as the EU. International standardization bodies publish international standards that reflect the consensus of the players operating on the global market.

For the estimation, the standardization variable is differentiated into a variable for the stock of national standards or norms *nno*, a second variable for the stock of European standards *eno*, and a third variable for international standards, *ino*. [16]

Including the differentiation of the standards, the regression equation, which initially only contains the standards but is then supplemented by further elements of the QI, now looks as follows:

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 nno_{it} + \lambda_5 eno_{it} + \lambda_6 ino_{it} + u_{it} \tag{6}$$

4.2.1.2. Metrology. We measure proxy metrology by metrology standards in ICS 17, leading to models which are structurally similar to Eqs. (5) and (6).

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 summetno_{it} + u_{it} \tag{7}$$

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 nmetno_{it} + \lambda_5 emetno_{it} + \lambda_6 imetno_{it} + u_{it} \tag{8}$$

4.2.1.3. Conformity assessment and accreditation. We test conformity assessment and accreditation in one model with the ISO 9001 certifications and the IAF-membership variable.

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 iso9001cert_{it} + \lambda_5 iafmemb_{it} + u_{it} \tag{9}$$

4.2.1.4. Market surveillance. Market surveillance is captured by the number of surveillance notifications.

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 rapex_{it} + u_{it} \tag{10}$$

4.2.1.5. Summary model of all QI-elements. Finally, to obtain an overall estimate of the economic effects of QI on GDP, we estimate a summary model, which simultaneously includes variables from the four QI-dimensions, i.e. standards, conformity assessment, accreditation and market surveillance. Our model looks as follows:

$$y_{it} = \alpha_0 + \alpha k_{it} + \beta l_t + \lambda_1 rd_{it-1} + \lambda_2 pat_{it} + \lambda_3 lic_{it} + \lambda_4 sumno_{it} + \lambda_5 iso9001cert_{it} + \lambda_6 iafmemb_{it} + \lambda_6 rapex_{it} + u_{it} \tag{11}$$

4.2.2. *Causal identification*

Achieving causal identification in the key equations remains a challenging task due to various issues, some of which relate to conceptual problems, others to data limitations, and others to issues in econometric identifiability using field data. We will now briefly describe these issues one by one.

Conceptually, the five elements of QI are not isolated but exist in complex relationships, which differ depending on the country's institutional setting as well as between sectors. Whereas standards form the basis for conformity assessment, accreditation, and metrology, market surveillance is also grounded in regulations. Additionally, accreditation can enhance trust in certification bodies. However, there are also recursive relations, e.g., conformity assessment bodies trigger the development of standards to secure and expand their market for certifications. Metrology standards are a small subcategory of standards, but they have only limited economic implications for the measurement products market. Market surveillance in the European Union member states mainly refers to mandatory regulations. Still, it is not so closely linked to standardization and standards as the main elements of QI. In summary, the various aspects of QI generally build upon one another. Still, there are also recursive relationships and other external framework conditions, e.g., regulations, which have implications for the economic value of QI. Thus, not easy to model the correct dependence structure.

In addition to the conceptual complexity of the QI, we must acknowledge severe data limitations. Although the stock of standards has been used as an indicator reflecting the QI component of standards in numerous studies in the past (ISO, 2021), it has the limitation that it does not reflect the actual diffusion of standards. Related to metrology, specific metrology standards and metrology patents can be utilized, as has been done in the past. Although we have a good data situation concerning ISO 9001 certifications as indicators of conformity assessment, it is worth noting that, for example, self-declaration by companies and testing activities cannot be fully covered due to a lack of data. Entry into the IAF forum can be used as a source of information on accreditation, but it is a very coarse indicator. Finally, the approximation of market surveillance by the cases reported in RAPEX is the only option, but it overlooks the diverse resources and cultures within countries.

Finally, econometric issues can arise from the fact that the QI typically coevolves with the local economy and other elements of the regulatory, legal, and institutional frameworks in specific countries and regions. This coevolution can make it challenging to identify clean causal effects. In the absence of clear quasi-experimental settings, our data suggest that we must resort to econometric techniques to control for resulting endogeneity issues as much as possible. Yet, since we do have access to panel data, we can control for unobserved heterogeneity across countries, which is a primary source of concern. We control for unobserved heterogeneity by using fixed effects regression in conjunction with the explicit modelling of reasonable time lags between cause and effect (see Eqs. (3)–(6)).

Nonetheless, the simultaneous existence of conceptual, data-related, and econometric issues implies that our results should be interpreted as indicative, providing approximations of the order of magnitude of the effects rather than clearly identifying causal effects.

5. Results

In the following chapter, we present the results of the regression analysis first separately by the elements of QI and eventually in a comprehensive model.

Initially, we begin with the most intensively investigated aspect of QI, the standards, which are generally described in Eqs. (5) and (6). The results related to these equations are presented in Table 3, where columns 1–4 include the regionally separated standards individually and then simultaneously. In Column 5, we include the total stock of standards. Indeed, many of the effects are significant. Moreover, they also have an important interpretation in terms of magnitude. The significant elasticity of 0.018 on the total stock in Column 5 indicates that a hypothetical 10 % increase in the total stock of standards from 2019 to 2020 would contribute 0.18 % of GDP in the countries included in the panel.

To quantify the contribution of the stock of standards to GDP, the approach proposed by Blind and Schubert (2024) can be applied, in contrast to earlier approaches based on the contribution to growth (e.g., Jungmittag et al., 1999). If no country were to maintain a stock of

[16] In a study on the benefits of European standards, a distinction was made between harmonized European standards and non-harmonized European standards (see also European Commission, 2022). However, this information is not available at country level.

Table 3
Influence of standards on GDP.

	(1)	(2)	(3)	(4)	(5)
	Log GDP	Log GDP	Log GDP	Log GDP	Log GDP
Log population	−0.23535***	−0.22691**	−0.30622***	−0.29238***	−0.22433**
	(0.09041)	(0.09191)	(0.08514)	(0.09581)	(0.09111)
Log capital stock	0.18581***	0.19489***	0.18734***	0.20182***	0.17761***
	(0.03765)	(0.03853)	(0.03732)	(0.03885)	(0.03741)
L.Log R&D exp.	−0.03409	−0.02868	−0.04906**	−0.04443*	−0.04018*
	(0.02389)	(0.02415)	(0.02431)	(0.02496)	(0.02402)
Log trans. Patent appl.	0.17533***	0.16862***	0.18984***	0.18339***	0.17880***
	(0.01423)	(0.01486)	(0.01503)	(0.01632)	(0.01428)
Log license payments	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Log stock intern. Stds	0.01577*			−0.01898	
	(0.00927)			(0.01879)	
Log stock eur. stds		0.01222*		0.01625	
		(0.00705)		(0.01194)	
Log stock nat. stds			0.02778***	0.03299**	
			(0.01039)	(0.01387)	
Log stock stds					0.01832*
					(0.00955)
Constant	28.53948***	28.34109***	29.69469***	29.32198***	28.42202***
	(1.57681)	(1.61915)	(1.44560)	(1.66711)	(1.57206)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	347	347	347	347	347
R2	0.916	0.916	0.917	0.917	0.916
N_g	16	16	16	16	16

Standard error in brackets; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

standards (i.e., stocks would be reduced by 100 %), this would result in a GDP loss of 1.8 % (−100 % × 0.018). For the Federal Republic of Germany, with a GDP of just over 4 trillion euros, this would have been around 72 billion euros in 2023.[17]

As the stock of standards has only risen slightly in recent years compared to previous periods (Jungmittag et al., 1999; Blind, Ramel, & Rochell, 2022), and economic growth has only progressed moderately or stagnated, and even declined in various crisis years, we have decided to use the original quantification approach no longer. This is because the stock of standards would then have a significantly negative contribution to economic growth in recession years, which is neither theoretically justified nor empirically observable at the company level, both in terms of participation in standardization processes (Wakke et al., 2016) and the implementation of standards (e.g., Arocena et al., 2021). Instead, we now calculate the contribution of standards to GDP as a whole, rather than their change, which increases the robustness of the results because economic fluctuations or crises have only a limited influence on the estimation results.

With regard to metrology, the national, European, and international metrology-relevant standards can be separated from the total stock of standards in order to estimate the specific impact of metrology as described in Eqs. (7) and (8).[18] They account for less than 5 % of the total standards. However, it can again be shown that the national metrology standards have a significant impact on GDP (see Table 4), while the European metrology standards have no impact, and the international metrology standards even have a negative impact. Overall, however, the metrology standards have no significant influence on GDP, so that they are not considered further in the further analysis of the effects of the QI elements.[19]

In a further step, this basic model for the economic impact of standards, which has been proven by the numerous earlier studies mentioned above, is used to approximate the conformity assessment using the data provided by ISO on certificates issued by accredited conformity assessment bodies for the international quality management system standards series ISO 9001 and to estimate their contribution to GDP (see Eq. (9)) .[20] Unfortunately, it is not possible to differentiate between certificates issued by accredited and non-accredited conformity assessment bodies. For this reason, entry into the IAF is used to measure the impact of accreditation.

Both the number of ISO 9001 certificates and membership of the IAF make a significant positive contribution to GDP (compare Table 5). The strength of the influence is even higher than that of the standards. Analogous to the quantification of the economic contribution of the standards portfolio, this can also be carried out for the conformity assessment, i.e. if the ISO 9001 certifications were declared invalid or the IAF memberships were canceled, this would mean a GDP loss of 4.9 % (−100 %**0.049) or 9.3 % (−100 %**0.093). For the Federal Republic of Germany, with a GDP of just over 4 trillion euros, this would be approximately almost 200 billion euros and 400 billion euros respectively in 2023.

Finally, the effect of market surveillance is calculated based on Eq. (10). As explained above, the information from RAPEX is used to

[17] In 2000, the benefit of standardization on economic growth, i.e., the change in GDP, was estimated at around 16 billion euros (DIN, 2000). In an update in 2011, the contribution to economic growth was just over EUR 13 billion (Blind, 2024). With a GDP of 4 trillion euros, this would translate to 7.2 billion euros in the case of Germany, assuming an elasticity of 0.018 and a 10 % increase in standards. This is approximately half of the value determined in the DIN study from 2000 (DIN, 2000) and can be explained by the fact that the results of the study at that time were based on long-term historical data exclusively from Germany, where, on the one hand, there was even stronger growth in the stock of standards and, on the other hand, Germany was able to derive greater economic benefits from its active participation in standardization bodies compared to other countries.

[18] Alternatively, scientific metrology can also be approximated by metrology patents. However, the regression estimates showed significantly negative coefficients, so this approach was not pursued further.

[19] In a previous study, Temple and Williams (2002) find a significant impact of measurement R&D of 2 % of the GDP of the United Kingdom.

[20] We use the time series for ISO (2022) because they extend longer into the past and also because their high number reflects the general character of a country with regard to conformity assessment. It should be pointed out once again that a much larger panel of countries is available for this estimate.

Table 4
Influence of metrology standards on GDP.

	(1)	(2)	(3)	(4)	(5)
	Log GDP	Log GDP	Log GDP	Log GDP	Log GDP
Log population	−0.30638***	−0.26022***	−0.23150***	−0.29192***	−0.28403***
	(0.09137)	(0.08816)	(0.08733)	(0.08938)	(0.09136)
Log capital stock	0.17936***	0.17790***	0.17502***	0.17238***	0.17891***
	(0.03760)	(0.03755)	(0.03724)	(0.03678)	(0.03776)
L.Log R&D exp.	−0.03346	−0.02876	−0.05813**	−0.05656**	−0.03505
	(0.02409)	(0.02447)	(0.02533)	(0.02688)	(0.02416)
Log trans. Patent appl.	0.17590***	0.17150***	0.18808***	0.18895***	0.17613***
	(0.01428)	(0.01475)	(0.01485)	(0.01599)	(0.01432)
Log license payments	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Log stock intern. metr. stds	−0.00540			−0.03483***	
	(0.00832)			(0.01116)	
Log stock eur. metr. stds		0.00985		0.01332	
		(0.00811)		(0.00975)	
Log stock nat. metr. stds			0.02144***	0.03608***	
			(0.00816)	(0.01018)	
Log stock metr. stds					0.00047
					(0.00794)
Constant	29.92730***	29.06811***	28.81190***	29.89115***	29.54280***
	(1.55924)	(1.51657)	(1.47430)	(1.53016)	(1.55194)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	347	347	347	347	347
R2	0.915	0.915	0.917	0.919	0.915
N_g	16	16	16	16	16

Standard error in brackets; *p < 0.10, **p < 0.05, ***p < 0.01.

Table 5
Impact of conformity assessment and accreditation on GDP.

	(1)	(2)	(3)
	Log GDP	Log GDP	Log GDP
Log population	0.23039***	0.16833**	0.22406***
	(0.06604)	(0.06599)	(0.06483)
Log capital stock	0.23520***	0.22319***	0.24756***
	(0.01599)	(0.01580)	(0.01590)
L.Log R&D exp.	0.00432	0.00855	0.01970
	(0.01760)	(0.01797)	(0.01756)
Log trans. Patent appl.	0.08395***	0.09335***	0.07683***
	(0.01118)	(0.01102)	(0.01107)
Log license payments	0.00000***	0.00000***	0.00000***
	(0.00000)	(0.00000)	(0.00000)
Log ISO 9001 cert.	0.06302***		0.04905***
	(0.00793)		(0.00831)
Member IAF		0.13340***	0.09332***
		(0.01871)	(0.01941)
Constant	20.02264***	21.22942***	19.92522***
	(1.12187)	(1.10996)	(1.10116)
Year dummies	Yes	Yes	Yes
Observations	635	635	635
R2	0.860	0.857	0.865
N_g	30	30	30

Standard error in brackets; *p < 0.10, **p < 0.05, ***p < 0.01.

Table 6
Impact of market surveillance on GDP.

	(1)
	Log GDP
Log population	0.17583**
	(0.06819)
Log capital stock	0.21412***
	(0.01666)
L.Log R&D exp.	−0.00551
	(0.01846)
Log trans. Patent appl.	0.11017***
	(0.01102)
Log license payments	0.00000***
	(0.00000)
Log RAPEX	0.00971***
	(0.00252)
Constant	21.27979***
	(1.15274)
Year dummies	Yes
Observations	635
R2	0.848
N_g	30

Standard error in brackets; *p < 0.10, **p < 0.05, ***p < 0.01.

ultimately map all elements of the QI in the macroeconomic production function.

As Table 6 shows, even market surveillance, as approximated by the number of cases recorded in the RAPEX system, has a significant impact on GDP, albeit a minor one compared to standards and conformity assessment. Analogous to the quantification of the economic contribution of the standards, conformity assessment, and accreditation, i.e., if the ISO 9001 certifications were to be declared null and void or the IAF memberships were to be revoked, this would mean a GDP loss of 0.97 % (−100 %**0.0097). For the Federal Republic of Germany, with a GDP of just over 4 trillion euros, this would be approximately 40 billion euros in 2023.

While the various elements of the QI are included separately in the previous estimation equations, all components except for the insignificant metrology standards are included simultaneously in a further regression to determine the overall effect of the QI, as shown in Eq. (11).

The results are presented in Table 7, where we calculated several model variants to assess the robustness of this central finding. In the first column, we present the baseline Fixed Effects model, which has hitherto been used throughout. Column 2 shows the results for the Random Effects model. While Random Effects models can generally be biased when unobserved heterogeneity is significant, they are less susceptible to the effects of outliers. In Column 3, we present the results of the baseline model, but with QI elements lagged by one period. In Columns 4 and 5, we implement a sample split for high-income (predominantly North and Middle European) and medium-income countries, mainly from Eastern and Southern Europe.

Analogous to the calculation of the effects of the individual elements

Table 7
Simultaneous influence of the QI elements on GDP.

	(1)	(2)	(3)	(4)	(5)
	Log GDP	Log GDP	Log GDP	Log GDP	Log GDP
	FE	RE	Lags-QI	Medium Income	High Income
Log population	−0.34004***	0.44702***	−0.35092***	−0.38008	0.72906***
	(0.09360)	(0.05257)	(0.09098)	(0.24687)	(0.14407)
Log capital stock	0.18111***	0.20008***	0.18699***	0.11670	−0.04363
	(0.03728)	(0.03248)	(0.03628)	(0.08098)	(0.03175)
L.Log R&D exp.	−0.00725	−0.01863	−0.02556	−0.00412	−0.00493
	(0.02408)	(0.02774)	(0.02253)	(0.05212)	(0.02398)
Log trans. Patent appl.	0.16218***	0.22086***	0.16312***	0.19685***	0.01370
	(0.01584)	(0.01724)	(0.01525)	(0.02697)	(0.02652)
Log license payments	0.00000	0.00000	0.00000	−0.00000**	−0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
L1/Log stock stds	0.02716***	0.04839***	0.02962***	−0.01875	0.02474***
	(0.00932)	(0.01043)	(0.00794)	(0.03242)	(0.00533)
L1/Log ISO 9001 cert.	−0.01756**	−0.00261	−0.01067	0.03682	−0.00981
	(0.00871)	(0.00974)	(0.00731)	(0.03269)	(0.00993)
L1/Member IAF	0.07738***	0.07106***	0.09737***	0.05611*	0.32035***
	(0.01651)	(0.01931)	(0.01483)	(0.02859)	(0.03552)
L1/Log RAPEX	−0.00894***	−0.00063	−0.01014***	0.00376	−0.00036
	(0.00322)	(0.00358)	(0.00324)	(0.01260)	(0.00244)
Constant	30.06115***	16.13684***	30.32355***	30.61770***	15.20056***
	(1.62758)	(0.79381)	(1.57207)	(4.33196)	(2.31916)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	347	347	347	138	209
R^2	0.924	0.935	0.929	0.934	0.962
N_g	16	16	16	6	10

Standard error in brackets; *p < 0.10, **p < 0.05, ***p < 0.01.

of the QI on GDP, the sum of the significant coefficients of the QI elements are added together in the overall calculation, resulting in a value of 0.078 for the baseline model.[21] If all these QI elements were eliminated, this would mean a GDP loss of 7.8 % (−100 %**0.078). Consequently, for the Federal Republic of Germany in 2023, with a GDP of just over 4 trillion euros, this would have meant a loss of almost 320 billion euros in GDP. However, this substantial value fits in well with the dimensions of estimates from previous studies on the importance of conformity assessment and accreditation. The 2013 study by Technopolis & DIN, commissioned by the then Federal Ministry of Economics and Technology, attributed an economic significance of between EUR 213 billion and EUR 357 billion to conformity assessment in the Federal Republic of Germany. At the same time, Schöneberg (2020) found sales of EUR 22.5 billion in the investigation of the German industry for laboratory analysis in 2017. Assuming overall economic leverage effects of such infrastructures[22] of 10–15, this also comes to over 300 billion euros. In summary, the estimation approach used therefore yields entirely plausible values for the macroeconomic contribution of QI and for the loss of GDP in its absence.

Indeed, the result from the baseline model is also the lowest among the tested technical variants in Columns 1–3, suggesting that we can treat this value as a robust lower bound. For the Random Effects model, the elasticity is 11.9 %. For the one-period lagged QI elements, it is 11.6 %. What is interesting, though, is that the sample is split into high- and medium-income countries. This split shows that the effects are substantially larger for high-income countries, reaching elasticities of 34.5 %, but only 5.6 % for medium-income countries, where latter is based only on the marginally significant effect for IAF-membership. Thus, in summary, the estimated effects do not depend significantly on specific modelling assumptions. However, there is heterogeneity among the countries, with the economically leading countries benefiting substantially more.

6. Summary of the findings

Summarizing our results, while international standards and the broader quality infrastructure (QI)—including standards, conformity assessment, accreditation, metrology, and market surveillance—play a vital role in supporting economic development, their economic value has not been systematically quantified. Prior research has focused primarily on individual components, most notably the impact of standards, leaving the broader concept of QI underexplored. The existing studies are largely conceptual or based on case studies, and there is a lack of quantitative, econometric analyses that measure the combined and individual effects of QI elements on macroeconomic outcomes like GDP.

In addition to conceptual ambiguity around what constitutes QI—different definitions include or exclude elements such as market surveillance—the literature also suffers from data limitations. Reliable, time-series data across European countries for each QI component is sparse, and existing indicators often lack granularity or comparability. Moreover, the co-evolution of QI and national economies creates econometric challenges in identifying causal effects.

In this context, the study addresses two core gaps:

- The absence of a comprehensive and empirical model measuring the macroeconomic impact of QI.
- A need for robust indicators and econometric techniques to approximate the value of each QI component and the system as a whole.

To overcome these challenges, the study proposes and executes a panel regression analysis using data from European countries between 1990 and 2020. A Cobb-Douglas production function is extended to incorporate variables representing QI components, including national,

[21] In contrast to the individual calculation of the importance of conformity assessment and accreditation, we have a much smaller sample, which can explain the significantly negative coefficient of ISO (2022) certifications. In terms of content, the negative significance of conformity assessment can be explained by the first signs of decertification (e.g., Clougherty & Grajek, 2023).
[22] See also Blind (2024).

European, and international standards (from NAUTOS), ISO 9001 certifications as an indicator for conformity assessment, Membership in IAF for accreditation, metrology standards, and finally RAPEX alerts for market surveillance.

Key methodological features include Fixed-effects regression to control for country-specific unobservables, lagged variables to reduce endogeneity, and splits of the sample as a kind of robustness check. Finally, a shift has been made from measuring QI's contribution to growth to its contribution to total GDP, which is a more robust approach given fluctuating economic cycles.

The estimation progresses through three stages:

- Individual impact of each QI element (standards, conformity assessment, accreditation, metrology, and market surveillance).
- Comparative assessment of national vs. European vs. international standards.
- Combined model estimating the total economic value of QI by summing the elasticities of all significant components.

The results indicate that standards, ISO 9001 certifications, and IAF membership have a statistically significant and positive impact on GDP. Interestingly, market surveillance (proxied by RAPEX alerts) also contributes positively to GDP. Metrology standards, however, show no statistically significant impact in the aggregated model, likely due to their small share and measurement difficulties.

The study contributes to multiple strands of economic theory. First, by quantifying the role of standards and conformity assessment in economic performance, the study expands on the limited empirical research connecting QI to economic development. Second, through an adaptation of the Cobb-Douglas function to include QI indicators, the presented research provides an econometric framework for future QI-related assessments across regions or industries. Third, findings underscore the importance of trust-building institutions, like conformity assessment bodies, accreditation institutes, and market surveillance authorities, in market efficiency and reducing transaction costs. Finally, the work offers empirical support for policy initiatives that promote standardization, conformity assessment, accreditation, and surveillance infrastructure, aligning with ongoing efforts, e.g., by the EU and national governments.

However, the research reveals data limitations and conceptual complexities inherent in QI research, advocating for more granular, publicly accessible, and harmonized data sources. It is also the starting point for future causal analyses using instrumental variable approaches or natural experiments.

This study delivers the first comprehensive empirical assessment of the macroeconomic effect of quality infrastructure. Its findings underline that QI components are not merely technical tools but pivotal economic assets contributing significantly to national GDP. While limitations remain—especially in data coverage and causal identification—the study makes a foundational contribution to the understanding and valuation of QI, opening avenues for both academic research and evidence-based policymaking.

7. Discussion and policy implications

Upon reviewing the overall results, we draw the following conclusions. On the one hand, the investigations confirm the importance of the stock of standards, especially for GDP, as identified in numerous studies in the past (ISO, 2021). The influence of metrology standards is fundamentally similar to that of the entire body of standards, while metrology patents are not suitable for measuring the effects of metrology. However, an appropriate and more specific indicator for metrology must be included in future studies. A database of the calibration and measurement capacity (CMC) of its member countries has been built by the Bureau International des Poids et Mesures (BIPM). However, sufficiently long time series are not yet available.

In contrast, the generally good data coverage about ISO 9001 certifications helps to estimate the influence of conformity assessment. The results also align with earlier studies on their impact on foreign trade (Swann, 2010). Participation in the International Accreditation Forum (IAF) as an indicator for accreditation plays a significant role in the country panel analyses. However, the approximation of market surveillance by the cases reported in the European Rapid Alert System for Dangerous Products (RAPEX) must be critically assessed due to the ambivalent results.

Our results for the income-level splits reveal that the economic effects are much larger for high-income countries. Consequently, their investments in QI generate a significantly higher return on investment than those in medium-income countries. This might be driven by the more prominent representation of high-income countries in standardization processes, which create advantages not only in terms of standards being closer to their technological capacities but also in relation to market preferences, as well as conformity assessment relying on these standards. There is obviously a stronger virtuous circle between QI and GDP for high-income countries, which can only be reached by countries with lower income by higher investments in QI or benefiting from positive spillovers from the QI of high-income countries via trade or foreign direct investment.

Overall, the regressions represent the first attempt to quantify the economic impact dimensions. The values determined for Germany are also in line with the results of previous studies, which are based on limited databases and rigorous assumptions. Nevertheless, measuring some components of the QI is challenging due to missing data, a problem that may not be easily resolved soon. Furthermore, we have not yet considered interactions between the elements of QI, as the initial attempts did not yield robust results. Finally, we should have employed methodological approaches that allow us to establish causal relationships. Here, more complex instrumental variables need to be constructed to address the endogeneity problem, or we must identify policy interventions or other quasi-experimental settings. For some approaches, external interventions exist, such as the consolidation of the accreditation system in Germany, but not for the system as a whole. These experiments would be more limited than our study, but they could estimate specific aspects of our impact model with greater accuracy.

A further limitation is in scope. Our study firmly focused on GDP and thus purely economic outcomes. Given that endogenous growth depends on innovation, a key question is how the QI affects and is in turn affected by innovation activities. More generally, our proposed impact model is much richer than our more limited econometric model. In this respect, while our exploratory analysis provides significant insights for the emerging literature seeking to understand the role of the QI, many of its aspects remain only vaguely understood. In that respect, our impact model may guide future work towards essential research questions. Specifically, beyond testing only the final effects of the QI on GDP, a fruitful area of research could focus on disentangling the numerous direct and indirect pathways through which science, innovation, the QI, and economic outcomes are linked.

Based on the findings of our study, several policy recommendations can be derived. These findings are grounded in empirical evidence demonstrating the positive macroeconomic impact of standards, conformity assessment, accreditation, and market surveillance across European countries. First, the capacity to develop standards on the national, as well as European and international levels, should be strengthened, because standards have been found to contribute significantly to GDP. In particular, national, European, and international standards bodies should be supported to encourage broader participation from SMEs, research institutions, and industry in the standard-setting process, which will also promote the implementation of these standards. Furthermore, the development of standards aligned with economic priorities, such as green technologies or digital transformation, should be reinforced in the future. Second, the widespread adoption of quality management system standards should be promoted, as ISO 9001 certifications, serving as a proxy for conformity assessment, have shown a substantial and statistically significant effect on GDP. In particular, incentives (e.g., subsidies, tax credits) should be provided for firms—especially SMEs—to implement ISO 9001 and similar quality management systems. Third, the International Accreditation Forum (IAF) should be further enhanced, as IAF membership has been associated with positive economic effects, highlighting the role of internationally recognized accreditation. It should be ensured that national accreditation bodies maintain membership in IAF as a multilateral recognition arrangement, which will institutionalize their capacity. Furthermore, the mutual recognition of accredited conformity assessments should be promoted to reduce trade barriers and foster greater cross-border trust. Fourth, standardization related to metrology should be strengthened, like standardization in general, as mentioned above. Fifth, market surveillance has to be strengthened, because market surveillance (proxied by RAPEX alerts) was found to have a positive contribution to GDP. Specifically, the funding and staffing for market surveillance authorities, particularly in sectors with high consumer risk or economic relevance, have to be raised to increase not only their economic, but also their social impact. Additionally, data from RAPEX and similar systems should be utilized more proactively to inform policy and regulatory adjustments. Fifth, investments in the QI should be considered a growth strategy, given its significant total contribution to GDP. Specifically, the QI should be integrated into national and EU industrial strategies, innovation policies, and economic development plans. The QI should be perceived as an economic enabler, not just a (self-) regulatory tool. Its funding should be prioritized in national budgets and EU programs, complemented by raising awareness of its economic benefits, e.g., by considering it in policy impact assessments. Its higher impact in high-income countries should incentivize low-income countries even more to invest in QI, thereby benefiting more from the virtuous circle between QI and economic development. Finally, our study highlighted limitations in the availability and consistency of QI-related data, particularly in relation to metrology and market surveillance, which require improving data collection for all QI elements, including their interactions.

CRediT authorship contribution statement

Knut Blind: Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Peter Neuhäusler:** Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Torben Schubert:** Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2025.103114.

Data availability

Data will be made available on request.

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