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Two Sides Of The Same Coin? A Panel Data Approach To The Innovation-Standard Relationship

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Abstract: Previous studies have shown an ambivalent relationship between standards and innovation while emphasizing the need to clarify the relationship and uncover their possible causal link. This paper revisits the standard-innovation relationship with the ISO 9001 standard, and patents applications as indicators of standards and innovation, respectively. Using a panel dataset of 81 countries covering the period 1993-2019, we find that ISO 9001 certification is positively associated with innovation. Our fixed-effects and system GMM estimates show that doubling the number of ISO 9001 certificates obtained at the national level increases innovation by 1.3-2.2%. The results vary according to the edition of the standard and the countries' level of development, whereby OECD countries seemed to benefit more from the international quality management standards more than non-OECD countries. The paper also suggests that official development assistance (ODA) may be a vehicle through which wealthier countries can help those from the Global South harness the benefits of standardization.

Keywords: Innovation; Patents; Standardization; ISO 9001

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Highlights:

1. ISO 9001 certification is positively associated with innovation.
2. The effect of international certification varies between OECD and non-OECD countries.
3. Official development assistance (ODA) is a possible vehicle through which countries from the Global South can harness the benefits of standardization.

1 Introduction

Do standards hinder or promote innovation? Previous research has presented contrasting results (Manders, de Vries, and Blind, 2016; Blind, 2013). At first glance, standards and innovation may appear to be mutually exclusive. By definition, a standard is expected to be used repeatedly and therefore will remain static for a specific period, whereas innovation has a dynamic or disruptive component (Andersen, 2013). Consequently, an emerging innovation offering a better solution while a prevailing standard is still in use, would have difficulty penetrating a market, especially if the switching or conversion costs are very high, or if the industry is characterized by monopolistic or oligopolistic firms enjoying IP rights (Kang and Bekkers, 2015; Farrell and Simcoe, 2012). Seen in this way, standards hamper innovation (de Vries, 2006). One can appreciate the lock-in effect caused by old technologies through the QWERTY keyboard. It has been fully embraced despite innovative keyboards with increased speed and better ergonomics. Switching to a different type of keyboard will require coordination among, or a simultaneous adoption by, all users including keyboards producers and typists (David, 1985; MBS, 2021). Fax machines are another illustration of the obstructing role of standardization. They have been around since 1842 and continue to be the de facto standard in legal and medical fields even though internet-based innovations such as emails, instant messaging, and cloud computing would allow a much speedier information sharing. The call to replace this obsolete technology received renewed interest in the Netherlands when the number of COVID19-related hospitalizations soared and the need to access patients' medical records much faster became a race against the clock (BBC, 2021).

Although outdated technologies can impede the advent of potentially superior new standards (Farrell and Saloner, 1985), it has also been argued that standards can support innovation. For de Vries (2006), standards are a prerequisite for innovations since without them, an innovation will remain at the mere stage of invention. Similarly, Swann and Lambert (2010) following a survey of the existing literature on standards and innovation find that standards positively affect innovation by strengthening customers confidence in new products in terms of acceptable safety, health and environment-related risks. Additionally, through the process of standardization knowledge is codified and shared, which gives firms participating in technical committees insider information or a leg up regarding emerging technologies (Blind, 2004, 2006; Bar and Aija, 2014). Standards also contribute to innovation by allowing compatibility or interoperability. In so doing, innovative ventures are more focused on developing complementary technologies enabling innovative firms to take advantage of economies of scale and invest their profits into innovation-generating activities (Blind,2013).

Empirically, the relationship between standards and innovation has mainly been examined at the firm-level using surveys. Using patent and standards data from Germany, Blind (2004) and Konrad and Zloczysti (2010) found a positive correlation between patenting and standardization activities, although a causal effect was not established. In the same vein, Swan and Lambert (2010), taking advantage on the British Community Innovation Survey, concluded that standards both promote and constrain innovation. Standards promote innovation by providing codified knowledge, but at the same time limit innovation as firms need to abide by strict health and safety regulations. Unexpectedly, their results showed that firms facing stringent standard-related regulations are more innovative compared to those that do not. They argue that because any standard or group of standards contain simultaneously information

(codified knowledge) and regulatory (constraining) aspects, firms limited by the regulatory component become more efficient at using the "codified knowledge" part of standards to innovate.

Other studies have found a positive effect of standardization on innovation depending on the type of innovation, the type of standard or the methodology adopted. For instance, Frenz and Lambert (2012) and Mangiarotti and Riilo (2010) relying on the Community Innovation Survey from Luxembourg conclude that certification to a quality management system, specifically ISO 9000, increases the probability of innovation depending on the definition of innovation or the sector a company operates in. The positive effect appears when they extend their definition of innovative companies to include those engaged in organizational and marketing innovations. However, with a restrictive definition of innovation, ISO 9000 certificates increase the likelihood of technical innovation in the manufacturing sector and of non-technical innovation (organizational and marketing innovation) in the service sector. Other studies have used Research and Development (R&D) expenditures as a proxy for innovation and found that standardization positively influenced innovation (Blind, 2013).

Overall, previous macroeconomic, microeconomic, and qualitative research have stressed the existence of a dual relationship between standards and innovation without establishing any causal link between the two concepts, in part due to the endogeneity of standardization. Endogeneity may happen because countries that acquire more certificates or standards may be different from those that do not. Thus, Researchers have emphasized the necessity for future studies to use complementary data or methods to address that issue (Blind, 2013).

The current paper re-examines the relationship between standards and innovation with a focus on a quality management standard, hence ISO 9001, using panel data from 81 countries covering the period of 1993 to 2019. The focus on a quality management standard rather than a technical standard which may have a more direct effect on innovation resides on the former's ability to affect innovation through continual improvement. Unlike previous studies which used firm-level data, surveys, qualitative, or sector-specific analysis, our study uses a dataset that covers both OECD and non-OECED countries over a longer time period. Our panel fixed effects and panel dynamic approaches are also an attempt to identify a causal relationship between ISO 9001 and innovation. Furthermore, using a quality management system standard, in ISO 9001 certification, as an indicator of standards seems appropriate because of its uptake and wider application regardless of the organization size, product line, sector of activity, or country's level of development. Although most ISO 9001 certificates are issued to companies, which will improve their performance by reducing information asymmetries, transaction costs, and increasing market share, these firm-level gains can translate into country-level benefits through several channels. For example, thriving businesses compete against each other and create jobs which may lead to productivity and economic growth, with implications for government fiscal budget and revenue. Similarly, better firms' access to foreign and domestic markets is likely to broaden the tax base. Governments in turn can spend tax revenues on research and development which will foster innovation. Likewise, ISO 9001 certification may attract foreign direct investment which will lead to foreign technology adoption and best management practices sharing depending on the countries' level of economic development.

As of 2019, more than a million valid ISO 9001 certificates were available worldwide compared to 46,571 certificates in 1993 (ISO, 2019), which is an indication of the increasing value that organizations see in certification. To date, ISO 9001 has undergone four revisions since its inception in 1987. The first occurred in 1994, the second in 2000, the third in 2008, and the

fourth in 2015 (ASQ, 2022). Thus, it would be important to consider whether the various revisions had an impact on innovation.
We are not aware of any previous cross-country studies examining the link between ISO 9001 and patents covering a similar timeframe for both countries from the Global North and Global South. Our approach also follows in the footsteps of several other studies examining the relationship between international certificates such as ISO 9001 and macroeconomics indicators such as Gross Domestic Product (GDP), foreign direct investment, tax revenues, government credit, or governance indicators (Marra da Silva Ribeiro et al., 2021; Marra da Silva Ribeiro et al, 2019; Salgado, 2015; Kalani et al., 2013; Clougherty and Grajek, 2008; Potoski and Prakash,2009).
Our results show that ISO 9001 standards have a positive and statistically significant effect on innovation. More specifically, doubling the number of national ISO 9001 certificates increases innovation, measured by the number of patent applications, by 1.3-2.2%. We also find heterogenous results by countries' level of development with countries from the Global North appearing to gain more from the quality management standards certification.
The remainder of the paper is structured as follows. Section 2 presents a brief overview of ISO 9001 and its theoretical link with innovation. Section 3 describes the data and our empirical strategy. Section 4 discusses the results, and section 5 addresses possible heterogeneities. Section 6 concludes.

2 Overview of ISO 9001 Certifications and Innovation

ISO 9001 belongs to the ISO 9000 family of standards that were launched in 1987. Since then, the number of certificates issued has significantly increased, making it the most popular standard of the International Organization for Standardization (ISO). In 2017 alone, there were 1,055,028 valid ISO 9001 certificates around the world (ISO, 2019). Besides reducing information asymmetries and ensuring that quality services and products meet customers and regulatory authorities' expectations, ISO 9001 quality management standard has been successful for its appeal to all types of organizations. Also, as part of the certification process an organization must provide evidence of conformity to a set of quality management principles or practices verifiable by a third-party auditor. That process can be expensive in the short term, but also cost saving in the long term, as internal operational costs are likely to fall due to the organization restructuring essential to fulfill the certification technical prerequisites.
ISO 9001 relies on eight management principles: customer focus, leadership, involvement of people, process approach, system approach to management, continual improvement, factual approach to decision making, and mutually beneficial supplier relationship (ISO, 2015). Those principles have been clarified and expanded in subsequent editions in 1994, 2000, 2008, and 2015. The 1994 edition put more emphasis on preventive actions, while the third edition focused on improving customer satisfaction, process approach, and active involvement of management. The 2000 edition of ISO 9001 also extended the concept of quality management to include continual quality improvement (Manders et al., 2016). The 2008 edition of ISO 9001 did not introduce substantial changes but rather provided more clarification to the concepts included in the previous version. Finally, the recent edition, ISO 9001: 2015, added a new requirement regarding identification and control of risks (Rybski, Jochem and Homma, 2017).

A number of firm-level and macroeconomic studies have highlighted the benefits of ISO 9001 certificates, and more generally of the ISO 9000 family of standards to exports sales, firm productivity, efficiency, errors and defects reduction, trade, foreign direct investment, and many other indicators of performance while also highlighting the motivations and barriers to adoption (Martincus, Castresana, and Catagnino, 2010; Goedhuys and Sleuwaegen, 2013; Clougerty and Grajek, 2008; Kakouris and Sfakianaki, 2018 ; Ferreira and Candido, 2021). However, when it comes to the relationship between standards and innovation, results are far from being conclusive, perhaps because of the lack of a common definition of innovation (Manders et al., 2016; Hashem and Tann, 2007), or the focus on traditional measures of innovation related to product or process.

In his pioneering work, Schumpeter (1934) considered innovation as "the commercialization of all new combinations based upon the application of new materials and components, the introduction of new processes, the opening of new markets, and/or the introduction of new organizational forms". Hence, innovation goes beyond an invention as the former is fully appreciated when it successfully makes it to the market. Innovation is a commercialized invention whose success is measured by the rate of adoption or diffusion of that innovation (de Vries and Verhagen, 2016).

In harmony with Schumpeter's approach, the Organization for Economic Cooperation and Development (OECD) defines innovation as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD /Eurostat, 2018).

The association between standards and innovation in general, and specifically between ISO 9001 and innovation, can be explained through the Technology Life Cycle (UNIDO, 1996; Egyedi and Sheriff, 2010; Riillo, 2009) and the eight Management Principles underlying ISO 9001. The Technology Life Cycle consists of four stages: emergence, improvement, maturity, substitution or obsolescence (Egyedi and Sheriff, 2010; Riilo, 2009). Egyedi and Sheriff (2010) use this framework to explain how standards and innovation co-evolve. According to them, standards are particularly relevant in the first three stages. For instance, even before a new product or process emerges, standards can play an anticipatory role aimed at solving potential problems as well as be a catalyst for the product or process entry into the market. The facilitating or enabling role of standards is further enhanced as the market grows and the new technology or product received additional refinements. This requires that standards be reactive or responsive to those improvements to alleviate market uncertainties. Similarly, as the innovation matures, standards need to be updated or revised until the product becomes obsolete, paving the way for a new product cycle (Riilo, 2009). Nonetheless, it is worth stressing that a product or process can become a de-facto standard, especially when everyone adopts it. The presence of a solution with popular acceptance or de facto standard, or dominant design can stimulate process innovation while reducing the possibility of radical innovation (Brem, Nylund, and Schuster, 2016). The inhibitory effect of standards on innovation may also result from the maintenance of standards such as amendments, corrigenda, or new versions (Egyedy and Blind, 2008).

Regarding the eight management principles underlying ISO 9001, Manders et al. (2016) argue that they can contribute to both incremental and radical innovation while conceding that in some cases radical innovation will be constrained. For example, through the customer focus principle, organizations are constantly challenged to develop new products and services that

will exceed customers expectations. Through the leadership principle, a leader is required to set clear goals and targets, inspire workers, provide resources and training, and allow the workers to share their ideas in an environment conducive to innovation. Similarly, the involvement or empowerment of people within the organization can create a free flow of communication between departments which will result in the development of an innovative behaviour. By means of the process approach, tasks are repeated and routinized, which will foster incremental innovation through learning by doing. In the system approach, the organization is viewed as a structure in which departments such as R&D, or marketing are interconnected, which might increase both incremental and radical innovation. In addition to the extensive analysis on how the eight management principles can impede or stimulate innovation, Manders et al. (2016) discusses mediating factors that can influence the link between standards and innovation. They conclude that the relationship may depend on the region, the sector, the firm size, and the standard version. We re-examine the relationship between ISO 9001 and innovation as well as possible mediating factors using a diverse panel of countries for the period 1993 to 2019.

3 Data and Methodology

3.1 Data

Our data came from four sources. Information on patent applications by residents is provided by the World Intellectual Property Organization (WIPO). The number of ISO 9001 certificates over the period 1993-2019 for each of the 81 countries (selected based on data availability) are taken from the 2021 ISO survey. We also use information from the World Bank Development Indicators (WDI) database. These country-year observations include expenditures in Research and Development as a percentage of GDP, education, and the proportion of the manufacturing or service sector in the GDP. Finally, the list of developed countries is found on the OECD website. Summary statistics of the sample data are presented in Table 1. Furthermore, before proceeding with our regression analysis, we present a bivariate relationship between our key variables of interest using simple scatter plots. Figure 1 shows a strong and positive correlation between patents and standards. As more ISO 9001 certificates are obtained, the number of patent applications to reflect innovation efforts increases. The positive association holds even when we take average patent submissions and standards as depicted in Figure 2. We also observe heterogenous results depending on the countries' level of development. Countries such as the UK, Germany, the US, Korea, Canada as well as emerging countries such as China, Brazil, India submit more patents in tandem with the number of ISO 9001 certificates received. The increase in the number of standards may have resulted from the national standardization strategies that those countries have implemented over the last decade (Blind and Mangelsdorf, 2016). These scatter plots provide suggestive evidence of the positive effect of ISO 9001 standards on innovation. In the next section we will present regression results with additional control variables.

Table 1: Summary statistics

	Source	Mean	Max	Min	SD	Obs
Log (patents application by residents)	WIPO	6.482	14.15	0	2.409	2054
Log (ISO 9001 standards)	ISO	6.921	12.88	0	2.599	2055
Log (R&D expenditure as % of GDP)	WDI	-0.315	1.600	-4.223	1.003	1522
Years of schooling, secondary	WDI	6.580	9	4	0.965	2182
Log (Total population)	WDI	16.58	21.06	12.48	1.646	2187
Manufacturing	WDI	0.443	1	0	0.497	2133
Service	WDI	0.481	1	0	0.500	2187
OECDE countries	OECD	0.457	1	0	0.498	2187

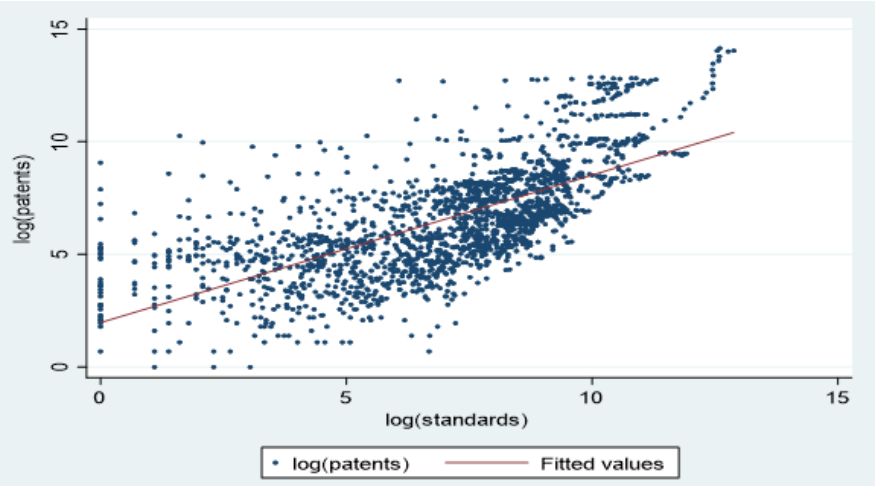

Figure 1: Scatter plot of innovation against standards (1993-2019)

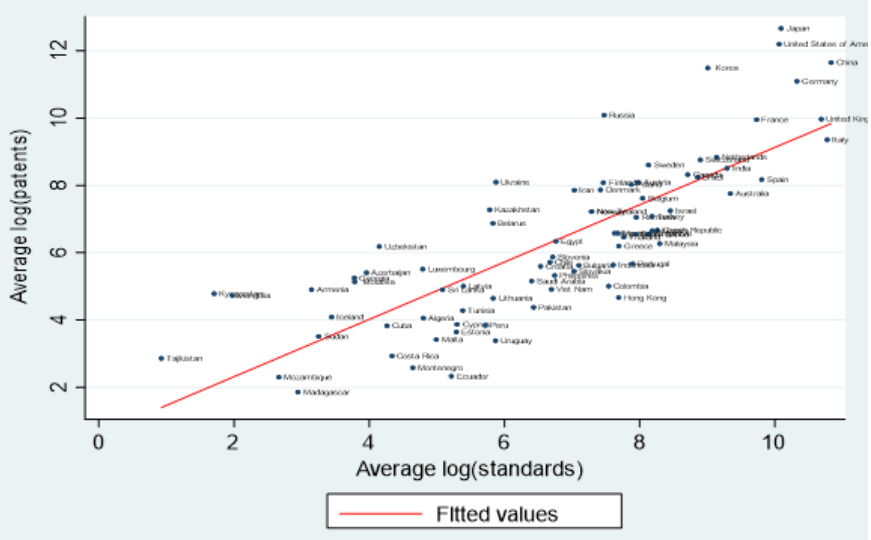

Figure 2: Scatter plot of average innovation and average standards (1993-2019)

3.2 Methodology

To examine the relationship between innovation and standardization we estimate the following model:

$$log(Patents_{it}) = \beta_0 + \beta_1 log(Standards_{it}) + \beta_2 log(Patents_{it-1}) + \beta_3 log(R\&D_{it})$$

$$+ \beta_4 log(Population_{it}) + \beta_5 Education_{it} + \beta_6 Year_{2000} + \beta_7 Year_{2008}$$

$$+ \beta_8 Year_{2015} + \mu_i + \varepsilon_{it} \qquad (1)$$

Where $Patents_{it}$ is the number of patent applications by residents in country i and year t. Previous research has shown that the number of patent applications is a good indicator of innovation (Tamura, 2016; Cefis and Orsenigo, 2001; Acs and Audretsch, 1989; Griliches, 1990; Schneider, 2005).

$Standards_{it}$ represents the number of valid ISO 9001 certificates existing in the respective countries and in year t. We hypothesize that there is positive relationship between patents (the proxy for innovation) and ISO 9001 certificates (Pekovic and Galia, 2009; Mangiarotti and Riilo, 2014; Wang et al., 2016).

$Patents_{it-1}$ is introduced to account for the dynamic or persistent effect of innovation (von Graevenitz, Wagner, and Harhoff, 2013; Wang et al., 2019, 2021). Furthermore, since patents are output of R&D activities, we expect a positive correlation between patents and R&D expenditures (Acs and Audretsch, 1989; Griffth, Redding, and Van Reenen, 2004). We also include $Population_{it}$ among our explanatory variables because as the population grows the demand for new products as well the promotion of new ideas, and thus innovation flourishes (Wang et al., 2019; Dong and Matin, 2017). $Education_{it}$ or human capital is also expected to stimulate knowledge sharing and accumulation, which in turn will foster innovation (Roper, Love, and Bonner, 2017; Arin et al., 2014; Wang et al., 2019).

$Year_{2000}$, $Year_{2008}$, and $Year_{2015}$ are year dummies included to capture the impact of successive standard editions or updates on innovation. It has been suggested that impact of ISO 9001 will vary depending on the standard edition (Wiele et al., 2005; Terziosky, Power, and Sohal, 2003; Manders et al., 2016). Therefore, in this study $Year_{2000}$ will be equal to 1 for the period 2000-2007 and 0 otherwise. $Year_{2008}$ will take the value 1 for the period 2008-2014 and 0 otherwise. Likewise, $Year_{2015}$ will be coded as 1 for the period 2015-2019 and 0 otherwise. μ_i represent the time-invariant unobserved heterogeneities in innovation across country and ε_{it} the idiosyncratic errors. To account for country-specific time invariant unobserved heterogeneities, we use panel fixed effects (FE) estimation methods. Moreover, to address potential issues related to the endogeneity of the regressors we also use a System General Method of Moments (Sys-GMM) estimator (Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). The endogeneity of standards for example may result from the fact that countries that acquire more ISO 9001 certificates may be different from those that do not, which will bias the result obtained from an OLS estimation technique. For instance, if the countries that were already doing well or benefiting from ISO 9001 certificates acquire

more certificates, the effect of ISO 9001 certificates on innovation will be overstated whereas the effect will be underestimated if countries with poor innovation records were acquiring more ISO 9001 certificates.
FE and Sys-GMM are our preferred estimation techniques, but we also present results based on OLS and random effects estimations.
In all our regressions we employ cluster-robust standard errors at the country-level to account for potential heteroskedasticity and autocorrelation of ε_{it}. In addition, except education and the year of standard editions, our dependent and independent variables are estimated in logs. Therefore, the associated coefficients ($\beta_1, \beta_{2,}\beta_{3,}\beta_4$) will be interpreted in terms of elasticities. More specifically, as percentage change in the dependent variable given a percentage change in the independent variable. The coefficient of interest is β_1 and is expected to be positive based on the rationale provided above.

4 Results

Table 2 presents the regression results of the impact of ISO 9001 certificates on innovation. Standards have a positive and statistically significant effect on innovation in almost all our regressions (Columns 1-7). The coefficients of the fixed effect regressions are positive and statistically significant at 1% and 5% level. When the number of ISO 9001 certificates increase by 1%, the number of patent applications increases by 0.022-0.179%. In other words, doubling the number of certificates increases innovation by 2.2-17.9% or the number of patent applications on average by 1 to 3 (Columns 3 and 4). Similar results are found for the SYS-GMM estimation. They indicate that doubling the number of ISO 9001 certificates increases innovation by 1.3% and the coefficient is statistically significant at 10% (Column 7). With a mean period of log ISO 9001 certificates granted of 6.921 (Table 1) an elasticity coefficient of 0.013 translates into 1 patent applications submitted on average[3]. In addition, the Hansen's test of over-identifying restrictions is satisfied at 1% significance level and the null hypothesis of no two-period serial correlation in the residuals cannot be rejected. The positive effect of standards on innovation is in line with the results found in previous studies (Pekovic and Galia, 2009; Mangiarotti and Riilo, 2014; Wang et al., 2016; Wayoro, Nonguierma, and Parkouda, 2023).
Looking at the other explanatory variables we see that the coefficient on lagged patents is closer to 1 and statistically significant at 1%, which means that innovation is highly persistent (Columns 2, 4, 6, and 7). This also shows the relevance of SYS-GMM results compared to the other estimation techniques. The coefficients on R&D expenditures are positive and significant at 1% level (Columns 2,4,6, and 7). This is consistent with innovation being an output of research and development (Acs and Audretsch, 1989; Griffth, Redding, and Reenen, 2004). Similarly, the coefficient on population is positive and statistically significant at conventional levels supporting previous findings suggesting that a larger population enhances innovation (Wang et al., 2019; Dong and Matins, 2017).
Turning to the versions of standards, results from Table 1 show that the 2008 and 2015 editions have negative and statistically significant effect on innovations (Columns 2,4,6, and 7). These results are different from those of Siougle, Dimelis, and Economidou (2019) regarding the positive effect of ISO 9001 successive editions on firm performance. However, the innovation-constraining role of new standards may be related to the information they contain. The technical

information within newly published standards take time to be fully understood, which can delay their wide adoption and prevent them from exerting their full impact (DTI, 2005). Manders et al. (2016) and Siougle et al. (2019) suggest that more studies are needed to fully analyse the dynamic effect of ISO 9001 and reach conclusions that hold, irrespective of the context.

Table 2: Effects of standards on innovation

	Pooled OLS		Fixed effects		Random effects		Sys-GMM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
log(standards)	0.655***	0.009	0.179***	0.022**	0.190***	0.011*	0.013*
	(0.019)	(0.008)	(0.034)	(0.010)	(0.034)	(0.006)	(0.007)
$\log(\text{patents})_{t-1}$		0.960***		0.784***		0.956***	0.957***
		(0.011)		(0.055)		(0.007)	(0.048)
log(R&D)		0.057***		0.148***		0.062***	0.058
		(0.021)		(0.034)		(0.013)	(0.075)
log(population)		0.037**		0.564***		0.040***	0.037
		(0.015)		(0.205)		(0.008)	(0.042)
Education		-0.002		-0.011		-0.001	-0.006
		(0.006)		(0.039)		(0.007)	(0.012)
Year_{2000}		-0.009		-0.027		-0.012	-0.016
		(0.026)		(0.020)		(0.019)	(0.021)
Year_{2008}		-0.061**		-0.065**		-0.065***	-0.059**
		(0.030)		(0.028)		(0.021)	(0.024)
Year_{2015}		-0.055**		-0.075**		-0.060***	-0.063***
		(0.027)		(0.029)		(0.018)	(0.022)
Constant	1.973***	-0.322**	5.318***	-7.890**	5.063***	-0.354***	-0.290
	(0.144)	(0.148)	(0.240)	(3.167)	(0.312)	(0.113)	(0.457)
R-squared	0.472	0.989	0.175	0.757	0.649	0.922	
Hansen test [p-value]							51.38 [0.207]
AR (1) test [p-value]							-2.58 [0.010]
AR (2) test [p-value]							-0.43 [0.669]
Observations	1952	1382	1952	1382	1952	1382	1382
Number of countries	81	81	81	81	81	81	81

Note: The dependent variable is log (patents). Robust standard errors are in parentheses, clustered by country.
Data sources: WDI, ISO, and WIPO
* significant at 10%, ** significant at 5%, *** significant at 1%.

5 Possible Heterogeneities

The level of economic development of a country and the sector in which firms operate are among the factors that may influence the relationship between ISO 9001 and innovation (Manders et al., 2016). To take the level of economic development into account, we split our

sample between OECD and non-OECD countries, and re-estimate equation 1. Results are presented in Table 3. They show a positive and statistically significant relationship between ISO 9001 certificates and innovation for OECD countries. Doubling the number of ISO 9001 certificates increase innovation by 1.4-4.9%. This may be explained by the existence of publicly funded research institutions, universities, industry clusters, and a strong competition and entrepreneurial spirit, which increase the number of standards produced and thus influence the relationship between standards and innovation (Manders et al., 2016; Aldabbas, Pinnington, and Lahrech, 2020). It is nonetheless possible that because firms in OECD countries have already advanced management systems in place, and more ISO 9001 certificates might not necessarily translate into increased innovation ability (Manders et al., 2016).

Table 3: Effects of standardization on innovation in OECD versus non-OECD countries

	Non-OECD		OECD	
	Fixed effects (1)	Sys-GMM (2)	Fixed effects (3)	Sys-GMM (4)
log(standards)	0.013	0.018	0.049***	0.014*
	(0.013)	(0.014)	(0.015)	(0.008)
$\log(\text{patents})_{t-1}$	0.740***	0.926***	0.844***	0.918***
	(0.091)	(0.049)	(0.035)	(0.049)
log(R&D)	0.143***	0.078	0.112**	0.145
	(0.040)	(0.052)	(0.051)	(0.097)
log(population)	0.814**	0.048	0.311	0.077
	(0.348)	(0.030)	(0.200)	(0.058)
Education	-0.065	0.005	0.039	-0.002
	(0.045)	(0.019)	(0.032)	(0.014)
Year_{2000}	-0.011	-0.013	-0.055***	-0.026
	(0.043)	(0.048)	(0.020)	(0.025)
Year_{2008}	-0.071	-0.083	-0.079***	-0.064**
	(0.057)	(0.059)	(0.028)	(0.027)
Year_{2015}	-0.063	-0.049	-0.107***	-0.085***
	(0.059)	(0.045)	(0.030)	(0.025)
Constant	-11.648**	-0.393	-4.532	-0.708
	(5.326)	(0.338)	(3.294)	(0.681)
R-squared	0.700		0.863	
Hansen test [p-value]		37.19 [0.757]		33.15 [0.884]
AR (1) test [p-value]		-2.10 [0.036]		-2.30 [0.021]
AR (2) test [p-value]		-0.95 [0.340]		0.77 [0.444]
Observations	634	634	748	748
Number of countries	44	44	37	37

Note: The dependent variable is log (patents). Robust standard errors are in parentheses, clustered by country.
Data sources: WDI, ISO, and WIPO
* significant at 10%, ** significant at 5%, *** significant at 1%.

To further analyze the heterogeneity of our results we follow the 2019 OECD classification of countries according to their level of development and divide our sample into Low- and-Middle-Income Countries (LMIC) versus non-Low-and-Middle-Income Countries. Likewise, the sample is segmented into countries receiving official development assistance (ODA) versus those that do not. Again, as presented in Table 4 our findings show a positive and statistically significant association between ISO 9001 certificates and innovation for advanced countries compared to countries receiving development aid. In addition, when considering our FE estimations, the magnitudes of the coefficients are much larger in OCED countries (Columns 1 and 5) compared to non-OECD countries (Columns 3 and 7). This suggests that standards contribute more to innovation in wealthier countries than those belonging to the Global South. Therefore, by increasing the capacity of the countries receiving ODA to engage in standardization, economically advanced countries can support innovation in the Global South and assist them harness the benefits of standardization as well. Indeed, despite the prohibitive cost of international standards for countries from the Global South, foreign aid can be used to increase access to those standards (Hudson and Jones, 2003).

One way in which that may happen is not only through the increase of ODA going to the Global South but also the review of aid categories, commitments, and disbursements so that they align with priorities related to Science, Technology, and Innovation (STI). They can also support domestic firms' capabilities through knowledge sharing and skills development for them to be able to reach the technological frontier. This is particularly relevant for LMIC where SMEs represent a significant part of the economic fabric. Another area where aid could be relevant is through the domestic standards infrastructure. For example, since the development of international standards requires the contribution of experts from National Standard Bodies, OECD countries can contribute to providing grants and supporting training activities aimed at strengthening the capacity of local volunteers during the standardization process.

***Table 4**: Effects of standardization on innovation by countries' level of development and official development assistance status*

	Non-LMIC		LMIC		Non-ODA		ODA	
	FE	Sys-GMM	FE	Sys-GMM	FE	Sys-GMM	FE	Sys-GMM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(standards)	0.027**	0.016*	-0.012	0.190	0.020**	0.001	0.009	0.013
	(0.011)	(0.008)	(0.032)	(0.206)	(0.008)	(0.007)	(0.014)	(0.027)
$log(patents)_{t-1}$	0.780***	0.945***	0.782***	0.624	0.742***	0.877***	0.795***	0.898***
	(0.061)	(0.027)	(0.077)	(0.464)	(0.059)	(0.049)	(0.071)	(0.063)
log(R&D)	0.159***	0.080*	0.070	-0.040	0.154***	0.184**	0.147***	0.124
	(0.042)	(0.045)	(0.064)	(0.727)	(0.047)	(0.076)	(0.047)	(0.090)
log(population)	0.540**	0.050*	0.904**	0.042	0.371	0.133**	0.748**	0.093**
	(0.222)	(0.028)	(0.361)	(0.326)	(0.234)	(0.061)	(0.331)	(0.037)
Education	-0.004	-0.003	-0.054	0.247	-0.043*	0.000	-0.002	0.034
	(0.044)	(0.010)	(0.055)	(0.215)	(0.025)	(0.011)	(0.061)	(0.049)
$Year_{2000}$	-0.028	-0.014	-0.025	-3.160	-0.012	-0.003	-0.016	-0.027
	(0.022)	(0.023)	(0.074)	(9.861)	(0.019)	(0.025)	(0.048)	(0.055)
$Year_{2008}$	-0.067**	-0.062**	-0.054	-2.877	-0.040*	-0.042*	-0.055	-0.079
	(0.033)	(0.027)	(0.101)	(8.314)	(0.021)	(0.024)	(0.065)	(0.077)
$Year_{2015}$	-0.082**	-0.068***	-0.045	-2.861	-0.063**	-0.062***	-0.049	-0.034
	(0.033)	(0.022)	(0.098)	(8.361)	(0.024)	(0.024)	(0.069)	(0.067)
Constant	-7.463**	-0.463	-13.897**	1.405	-3.981	-1.235*	-11.524**	-1.080
	(3.480)	(0.334)	(5.921)	(9.984)	(3.445)	(0.656)	(5.472)	(0.706)
R-squared	0.749		0.807		0.764		0.756	
Hansen test [p-value]		51.75 [0.197]		7.47[1.00]		36.15[0.794]		26.41[0.984]
AR (1) test [p-value]		-2.34[0.019]		-0.76[0.448]		-2.82 [0.005]		-1.99[0.047]
AR (2) test [p-value]		-0.18[0.854]		-1.23 [0.218]		0.99 [0.323]		-0.89 [0.373]
Observations	1204	1204	178	178	812	812	570	570
Number of countries	67	67	14	14	42	42	39	39

Note: see Table 2

In addition to the wealth-related heterogeneity in the standard-innovation relationship, differences may appear by sector of activities. Most of the studies dealing with the ISO 9000 families and innovation have been restricted to the manufacturing sector (Pekovic and Galia, 2009). However, the effect of ISO 9001 may vary by sector of activities (Riilo, 2014), especially with the service sector. Manders et al. (2016) suggest that the manufacturing and service sectors face different legislation, customers' expectations, and level of investments in R&D. All of this can influence the motivation to get certified and adopt standards, which in turn could affect innovation. To stress the importance of considering the sector of activities, we compare the GDP shares of services and manufacturing (value-added) for the countries in our sample. Figure 3 shows a clear distinction between the share of service sector and manufacturing sector in their economy. The share of services sector in the GDP is much bigger in OECD countries compared to the share of the manufacturing sector. The results seemed to be similar for most of the non-OECD countries. This suggests that not only the economic level but also the relative size of the manufacturing or service sector are important in examining the relationship between standards and innovation (Ettlie and Rosenthal, 2011; Viardot, Sheriff, and Chen, 2016).

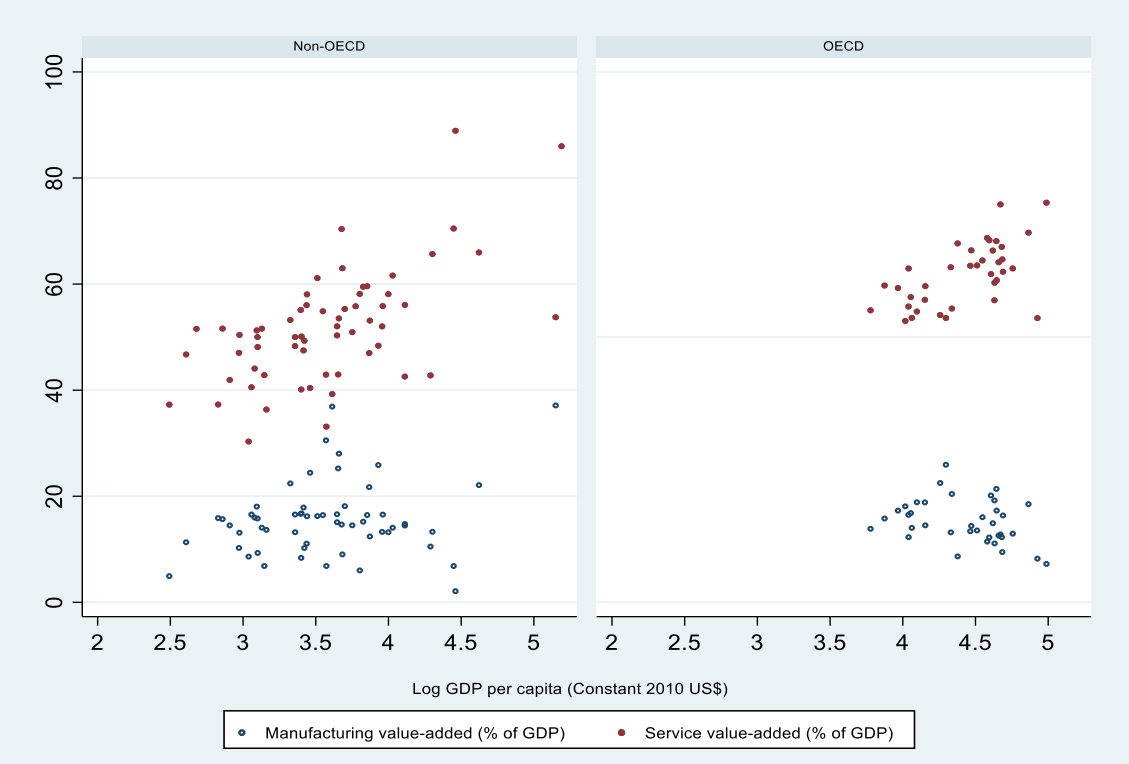

Figure 3: Comparing the contribution of the Manufacturing and Services sectors to GDP in OECD countries versus non-OECD countries (1993-2019)

6 Conclusion

This article has revisited the standard-innovation relationship using a panel of both OECD and non-OECD countries. Overall, we found a positive association between the number of patent applications (our proxy for innovation) and ISO 9001 certificates (our indicator for standardization). The positive relationship between standards and innovation corroborates previous findings which used surveys and/or qualitative research (Blind, 2013; Swann and Lambert, 2010; Mangiarotti and Riilo, 2010; Brem et al.,2016). The novelty in this paper is the use of the fixed-effects and system-GMM estimation approaches, aimed at addressing the endogeneity of standardization. Our estimations suggest that doubling the number of firms who are ISO 9001-certified will increase innovation (measured as the number of patent applications) by 1.3-2.2%.

There are two main limitations in this paper that are worth mentioning. The first one is our country -related proxy for innovation. While patents are frequently used as a proxy for innovation, it is not without limitations. Since innovation is a multidimensional concept, opting for the number of patent applications though accessible in terms of data gathering at the country level offers a view that could have been broader had we used an index of innovation. Also, we did not disaggregate patents by classes (process-oriented versus product), by citations, which could have helped us match them with similar information on standards and assess differences across industries or their value-added to the economy. The second limitation is the use of ISO 9001 as a metric for standardization. Though popular in terms of adoption, other international standards such as ISO 14001 (Environment), ISO 13485 (Medical device), ISO 27001 (Information Security), are used worldwide and could have an impact on innovation. Moreover, some studies examining the impact of standards rely on the stock of standards in a country, however the availability of this data can be severely limited. Hence the use of ISO 9001 as a proxy for standardization in the analysis of the relationship between standardization and innovation offers a perspective that could have led to different results if other standards were considered.-

Our findings also suggest that the level of development and the sector in which the firms operate matter. Similar to previous research, at the country-level several empirical studies have consistently shown a positive effect of standards on GDP and labor productivity growth (Blind and Jungmittag, 2008; Blind, Jungmittag, and Magelsdorf, 2011; The Conference Board of Canada, 2015). All of this underscores the benefits of businesses being certified to ISO 9001 for countries. While there are concerns that the cost of certification may be prohibitive, particularly for SMEs, our results indicate that certification leads firms to be innovative. Globally, it is estimated that 90% of businesses are SMEs and they account for more than half of job creation (World Bank, 2022). Given their major contribution to the world's economy, additional research using cross-country firm-level surveys may be worth pursuing to explore how firm sizes, sectoral differences, or location may influence the standard-innovation relationship. Despite the cost of certification, our research would suggest that businesses that depend on innovation for their competitiveness might find the investment worthwhile. A key finding of this study is that the relationship between standards and innovation can be influenced by a country's level of development, whether it is a recipient of official development aid and

the primary sector of activity. Additional firm-level survey research is needed to further explore sectoral differences. More research is also needed to understand how international versus domestic standards could impact innovation. Arguably, by fostering access to global markets international standards may have a more positive impact on innovation than domestic standards, however research is needed to confirm that hypothesis.

Finally, there are cases where patents are embedded in standards, referred to as standard essential patents. Further research should consider how this impacts innovation more broadly. Consideration should also be given to the timing of innovation or patent applications matched with the adoption of standards or the participation in standards setting committees (anticipatory standards), using insights from behavioural economics or industrial organization are worth investigating.

While previous research has found evidence that standards can at times foster and at other times impede innovation, our research indicates that ISO 9001 certification is positively associated with innovation. Importantly, this association was shown across 81 countries using longitudinal data from 1993-2019. Countries with a higher uptake of ISO 9001 benefit from greater innovation, even after controlling for factors that are known to drive innovation, demonstrating the value of standards for innovation.

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Conflict Of Interest (COI)

There is no conflict of interest.

Appendix: Countries in the sample

Algeria	Lithuania	Egypt	Singapore
Argentina	Luxembourg	Estonia	Slovakia
Armenia	Madagascar	Finland	Slovenia
Australia	Malaysia	France	South Africa
Austria	Malta	Georgia	Spain
Azerbaijan	Mexico	Germany	Sri Lanka
Belarus	Moldova	Greece	Sudan
Belgium	Mongolia	Hong Kong	Sweden
Brazil	Montenegro	Hungary	Switzerland
Bulgaria	Mozambique	Iceland	Tajikistan
Canada	Netherlands	India	Thailand
Chile	New Zealand	Indonesia	Tunisia
China	Norway	Iran	Turkey
Colombia	Pakistan	Israel	Ukraine
Costa Rica	Peru	Italy	United Kingdom
Croatia	Philippines	Japan	United States of America
Cuba	Poland	Kazakhstan	Uruguay
Cyprus	Portugal	Korea	Uzbekistan
Czech Republic	Romania	Kyrgyzstan	Viet Nam
Denmark	Russia	Latvia	
Ecuador	Saudi Arabia		