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The interplay between innovation, standards and regulation in a globalising economy

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ABSTRACT

To examine the different roles of regulation and standards in the age of globalisation, we hypothesize and investigate the relation of regulation and national and international standards on the one hand with innovation input (R&D expenditure) and innovation output (patents) on the other hand. The analysis is based on data of 26 high-income countries between 1998 and 2018. There are two main results. Firstly, international standards outperform both de-regulation and national standardisation as they are positively associated with R&D expenditure and patenting. On the other hand, national standards – once believed a source of competitiveness – are negatively related to patents and hence seem to localize economies and slow-down innovation. Secondly, de-regulation does not correlate positively with R&D expenditure, but with increased patenting. We argue the former suggest businesses did not – as assumed – spend freed up resources on R&D, but instead strategically used patenting to replace lost regulation-based protection with patent fences. This casts doubts on the added social value of de-regulation induced innovation.

1. Introduction

Regulation conditions firms' incentives to invest into and undertake innovation. The emergence of transnational production patterns and the dominance of the free trade paradigm challenges regulations in the age of globalisation (Baldwin, 2000; Gereffi et al., 2005). National regulations have been partly reduced via de-regulation or harmonized across countries to facilitate cross-border exchange of goods and services. De-regulation was intended to reduce administrative burden on firms freeing up resources for investment in R&D (Alesina et al., 2005) and to promote entry and competition to fuel innovation (Aghion et al., 2005). Simultaneously, national and in particular international standards were expanded (Büthe and Mattli, 2011). Governments increasingly delegated regulation to private national and international standardisation bodies. In the European Union, for example, regulations refer to or are based on standards developed at accredited European standardization bodies. Standards are considered more adept and dynamically adjusting to business operations (Blind et al., 2017), therefore equally reducing business administrative compliance costs and facilitating innovation. Finally, the harmonisation of regulation and international standards reduces the costs of entry in multiple markets, which should increase companies' incentives to invest in R&D and file patents that offer patent protection in all countries signing the patent cooperation treaty (PCT).

Although regulation and standards are controversially and prominently debated both in academia and policy-making, their empirical evidence on innovation is still inconclusive (Aghion et al., 2021; Amable et al., 2016; Blind et al., 2017; Litina et al., 2021). Existing empirical research focuses on a specific regulation, such as carbon emissions trading systems (Hu et al., 2020), firm size (Aghion et al., 2021), and chemicals (Chakraborty and Chatterjee, 2017) or applies panel analysis of countries (and if possible industries) over time based on the OECD's Product Market Regulation index (Amable et al., 2010, 2016; Blind, 2012; Litina et al., 2021). There is a substantial literature on the impact of standards on innovation, which is, however, rather rich in conceptual and humble in empirical evidence. Several authors have established conceptual frameworks regarding the economic functions of standards (Baldwin, 2000; Blind, 2017; Ganslandt and Markusen, 2001; Ho and O'Sullivan, 2018; Swann, 2000, 2010b; Tassey, 2017). There is no study

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thus far, according to our knowledge, which conceptualizes the relation between national vs. international standards and innovation. Existing empirical studies focus on the impact of standards on economic growth (e.g. Blind and Jungmittag, 2008) and international trade (Blind et al., 2018a,b; Chen and Mattoo, 2008; Raballand and Aldaz-Carroll, 2005; Swann, 2010a, b) rather than innovation. Finally, we are not aware of existing research that contrasts regulation and standards at the macro level, but only on the company level (Blind et al., 2017).

This paper contributes to the existing literature in the following way. We hypothesize and empirically examine the interplay between product market regulation, national and international standards on the one hand and R&D expenditure and patenting on the other hand. The analysis is based on panel regressions of 26 high-income OECD countries at the frontier of the world economy for which data on all main outcome and explanatory variables is available and where established, functioning standardisation and regulation frameworks exist between 1998 and 2018. Earlier research had shown national standards were a source of comparative advantage (e.g. Moenius, 2006; Swann et al., 1996). The results suggest that this does not hold true, at least for the average, in a globalised economy. Indeed, the model estimates suggest international standards outperform national standards and regulation both in terms of their relation to R&D expenditure and patenting. National standards, in contrast, seem to restrict economies and slowdown their innovation activities in a globalised world economy. While research has shown that regulation decreases firms' investment in R&D (Aghion et al., 2021; Litina et al., 2021), we illustrate that de-regulation, however, does not produce the symmetric positive effect: the results suggest that de-regulation does not correlate with increased R&D expenditure. Instead, firms must have invested freed-up resources elsewhere but not in R&D. At the same time, de-regulation correlates positively with patenting, which leads to the puzzle how innovation output can have increased even though R&D was unaffected. Based on existing literature, we argue that lost protection of the market position of incumbents based on de-regulation was replaced with increased protection based on patent fences.

The analysis captures regulation and standardisation across the 26 countries and over the years 1998–2018. We do not oppose the idea that in principle specific regulations or standards may have positive or negative effects depending on many contextual factors, such as industry or their respective implementation. Instead, we read the results as the aggregate and averaged interplay between regulation and standards on the one hand and innovation on the other hand across countries and over time.

In the following, section 2 embeds the analysis in the literature and derives hypotheses on how standards and regulation affect innovation in the form of R&D expenditure and patents. Section 3 presents the results of the empirical analysis, and section 4 discusses conclusions and implications.

2. Literature review and theoretical framework

Endogenous growth theory suggests technological progress drives economic growth (Aghion and Howitt, 1992; Grossman and Helpman, 1994). Technological progress is assumed to depend on the commercial incentives for profit-seeking firms to innovate, which we argue are dependant, in return, on regulation and standards of economies. Both standards and technical regulations for product markets have been defined in the World Trade Organization Technical Barriers to Trade Agreement in 1994 as the legal means to formulate rules for economic transactions in the world economy. While standards are developed – in theory – in national and international standardisation bodies by industry representatives, but also other stakeholders in technical committees based on a consensus-system, governments formulate regulation in a command-and-control fashion. Standards and regulation differ across countries, which international organisations and agreements have tried to attenuate based on harmonisation or mutual recognition of regulation and standards.

2.1. Standards, regulation and innovation in a globalising economy

As long as the market place is limited to a city or a country, national differences in regulation and standards would matter little (Baldwin, 2000; Büthe and Mattli, 2011). Idiosyncratic national regulation and standards that are not interoperable, however, substantially raise the costs of commercialising innovations in different countries (Baldwin, 2000; Blind et al., 2018a,b; Blind and Jungmittag, 2008; Chen and Mattoo, 2008; Fischer and Serra, 2000; Moenius, 2004; Swann et al., 1996) as national markets turn into global ones and as production and trade are organised in global value chains with specialisation and international division of labour (Gereffi et al., 2005; Kaplinsky, 2010; World Bank, 2020). Accordingly, multinational corporations often rely on own company standards to internalise across national subsidiaries (Blind and Müller, 2020; Gereffi et al., 2005). In addition, commercialisation of innovative products on consumer markets in high-income countries also requires active use of existing standards (Ho and O'Sullivan, 2018; Tassey, 2017). The semi-conductor industry supply-chains alone, for instance, uses more than one thousand standards (Tassey, 2017). Incremental and radical production innovation build on these existing international standards (Blind, 2017; Ho and O'Sullivan, 2018; Tassey, 2017), while idiosyncratic national standards may lock-in countries in another technology cycle or direction (Arthur, 1990; David, 1985; Swann et al., 1996; Tassey, 2017).

While regulation, national and international standards share the aim to create rules for fair competition and consumer protection, we examine in more depth in the following how their interplay with innovation may differ in a globalised world economy.

2.2. Regulation and innovation

One can conceptualise several mechanisms through which regulation can affect innovation (Conway et al., 2005; Crafts, 2006; McEntaggart et al., 2020). Conceptually, there have been two opposite hypothesizes about how regulation correlates positively with innovation. The less prevalent and more recently advanced view, which became known as the "Porter Hypothesis", stipulates that regulation can promote innovation (Ambec et al., 2013; Porter and Van der Linde, 1995). The ideas of the Porter Hypothesis is that – not all – but well-designed, stricter regulation may spur innovation through the following channels. Regulation may trigger creativity, help overcome organisational inertia or present bias, permit differentiation between brown and dirty products, put regulatory pressure to spur innovation of established firms, and promote R&D thanks to investment security and reduced uncertainty (Chakraborty and Chatterjee, 2017; Porter and Van der Linde, 1995). Extensions of the Porter Hypothesis are the "California" or "Brussel" effects showing that regulation in lead markets can be exported to and improve the performance of producers in foreign countries (Bradford, 2012; Vogel, 1997). Chakraborty and Chatterjee (2017), for example, show that as the German government (and later the EU) banned a specific chemical used in the production of textiles and considered harmful, R&D investment increased among those firms supplying the chemical relative to other firms in the chemical sector. Jaffe and Palmer (1997) find that pollution abatement costs correlate positively with R&D expenditure but not patenting. Song and Chen (2010), for example, do not only show that food safety regulation increased Chinese firms' expenditure on regulatory compliance expenditure, but also on technological innovation. However, Ramanathan et al. (2017) point to the requirement that regulations are also flexible to exploit their benefits related to innovation.

In the electricity sector, Cambini et al. (2016) find that the de-regulation of the EU market has increased patenting controlling for R&D expenditure. In a similar realm, Amable et al. (2010) find – in a sample of 15 industries for 17 OECD countries over the period

1979–2003 – that "the impact of regulation on innovation, even when negative far from the frontier, changes sign and is increasingly positive as one moves closer to the technological frontier". Recently, Quignon (2022) put innovation in the context of competition influenced by regulation. He reveals that reducing regulation intensifies domestic and foreign competition eventually increasing R&D expenditure and patenting. However, whereas domestic regulation directly led to growing R&D expenditure and patent production, competition induced by foreign regulation influences innovation via its effect on domestic competition. Overall, most of the studies that show positive effects of regulation on innovation are limited to environmental regulation (Popp, 2020; for examples see Jaffe and Palmer, 1997, Lee et al., 2011) and the export of regulations to low income countries (e.g. Chakraborty and Chatterjee, 2017; Vogel, 1997).

The prevalent view among economists, however, has been that regulation stifles innovation. Regulation has been coined as "red tape", "burden on business", "prone to capture" – essentially a barrier to innovation. From this perspective, regulation operates like a tax on business profits – compliance with the regulation generates costs, which reduce return to investment on innovation (Aghion et al., 2021; Besley and Burgess, 2004; Blind, 2012; Carlin and Soskice, 2006; Conway et al., 2005; Crafts, 2006; Palmer et al., 1995). In other words, the main postulated mechanism at play here is that government regulation may increase the costs of doing business through "regulatory compliance expenditures" that reduce the resources that firms have their disposal for R&D (Jaffe and Palmer, 1997; McEntaggart et al., 2020). Stewart (2011) provides the hypothetical example of "financial reporting regulation that may cause a firm to redirect resources away from its R&D division to its internal auditing division." In a recent paper, Aghion et al. (2021) find firm-size related regulation reduced innovation by 5%, which is mostly due to a reduction in R&D, but not in patent applications. Litina et al. (2021) find a 1% increase in product market regulation decreases firms' innovation activities by 1% in a sample of 12 European countries. This effect has been coined the "static compliance cost" effect (Blind, 2012; Carlin and Soskice, 2006; Crafts, 2006). Thus, according to this view, regulation drains firms' resources for investment in research and development, and de-regulation, in turn, promotes innovation as it increases the resources that firms have at their disposal to invest in R&D and innovate.[1] Given the OECD's product market regulation indicator captures product rather than environmental regulation, we assume that on the short to medium term:

Hypothesis 1. De-regulation correlates positively with expenditures on R&D.

In the following, we take a closer look at the conceptual link between product market regulation, competition and innovation. The OECD outlines that the product market regulation index is constructed "from the perspective of regulations that have the potential to reduce the intensity of competition" (Conway et al., 2005, p.3). Litina et al. (2021), for example, directly focus their literature review on the effect of competition on innovation even though the paper is about the effect of regulation on innovation. The study period 1998–2018 of this paper is indeed shaped by the expansion of liberal economic ideas and policies, including general and sector-specific de-regulation of industries, such as in telecommunications and public utilities.[2]

The main supposed effect of de-regulation is to promote competition (and thereby by assumption innovation). The central idea is that as governments de-regulate and remove regulatory barriers, they reduce the fixed entry costs, which should encourage new players to enter and compete for incumbents' profits. Assuming de-regulation induces competition the central question is how de-regulation induced competition affects innovation. Aghion et al. (2005, 2018a, b) argue that the effect of competition on innovation depends upon the level of competition. In industries with neck-to-neck competition, competition drives firms to innovate to escape from competitors. In industries where the distance to the frontier is too large, laggards or new players are discouraged from entry. Given the 26 countries in the sample are all high-income countries close to the technological frontier and given we focus on international applicable patent cooperation treaty patents, one can assume firms in the countries in our sample face neck-to-neck competition if not in their home countries than in international markets. However, the vacuum and uncertainty that de-regulation generates may induce incumbents with large market shares to innovate as de-regulation removes existing barriers for entrants and therefore creates an incentive to rebuild new regulatory barriers through patent fences (Cohen et al., 2002; Gilbert and Newbery, 1982; Walsh et al., 2016). The motivation to patent to distance or deter competitors is not new to economics. Gilbert and Newbery (1982) coin the term and theoretical concept of "pre-emptive patenting", which describes the incentive for a monopolist firm to pre-emptively patent to reduce entry as monopolist anticipate entry would reduce total industry profits. Importantly, not only does patents reduce competitors entry, they are in itself not necessarily of economic value to the patentee, thus called also a "sleeping patent". For example, Cohen et al. (2002) find that "80% of American and 93% of Japanese firm respondents report blocking as a motive", which leads the authors to conclude "preventing rivals from patenting related inventions – what we call "patent blocking" – was almost as pervasive as the prevention of copying as a motive for patenting." The authors also find about the same agreement to the motive "defensive patenting", which corroborates find from other studies (Blind et al., 2006). Several authors document that the problem has become more severe in the sample period and that pre-emptive patenting seems to positively correlate with competition (Cockburn and MacGarvie, 2011; Di Iorio and Giorgetti, 2020; Torrisi et al., 2016; Walsh et al., 2016). Walsh et al. (2016) find "greater patent effectiveness, more competition, and large firm size are associated with greater pre-emptive non-use relative to commercial use of patents. Di Iorio and Giorgetti (2020) find that "firms' lagged patents encourage firm's entry with new product while rivals' initial stock of patents discourages entry" in the pharmaceutical sector. Torrisi et al. (2016) conclude that "a large number of competitors spurs firms to accumulate patent fences, e.g. to pre-empt substitute innovations". Boldrin and Levine (2013) conclude "old and stagnant industries and firms lobby for stronger patent protection as it benefits them owners of patents and puts current and future innovators at disadvantage." Finally, Amable et al. (2010) argue that "product market regulation could […] lead firms to favour the cost-cutting dimension of competition rather than product innovation […], discourage them from undertaking risky innovative investment, or shift the focus on innovative activity on incremental modifications with little technological […] rather than more radical improvements." Based on the above, we argue that de-regulation increases patenting as firms seek to either rebuild lost protection from or deter new entrance.

Hypothesis 2. De-regulation correlates positively with the number of patent applications.

2.3. *Standards and innovation*

There is a substantial literature on the impact of standards on innovation, which is, however, rather rich in conceptual and humble in empirical evidence. Several authors have established conceptual frameworks regarding the economic functions of standards (Blind, 2017; Swann, 2000), the interaction of standards and technological progress (Ho and O'Sullivan, 2018; Tassey, 2017) or the role of standards for

[1] Note that the implicit assumption of this hypothesis is that firms invest resources freed-up by de-regulation into innovation (rather than other alternatives such as increasing dividends for shareholders).

[2] For example, John Williamson coined the term "Washington Consensus" – a list of 10 policy prescriptions including de-regulation and privatisation – which has become considered as the "recipe" of (neo-) liberal policies.

international trade (Baldwin, 2000; Ganslandt and Markusen, 2001; Swann, 2010a). The authors agree that the relationship between standards and innovation is conceptually ambiguous (Blind, 2016; Swann and Lambert, 2017) or, in other words, reason that standards could theoretically both help or hinder innovation. While the traditional view used to be that standards are a barrier to innovation, the more recent and prevalent idea is that standards are a catalyst or enabler of innovation (Blind, 2009; Choi et al., 2011; Swann, 2000, 2010b). Commonly, the literature discusses at least the following functions of standards for the economy: create interoperability and thereby enable economies of scale, reduce variety and thereby build focus and guide innovation, and create trust across borders. Existing studies that incorporate an analytical perspective of the effect of globalisation on the role of standards focus rather on protectionism or trade diverting effects of national standards, especially for firms in developing countries (Baldwin, 2000; Chen and Mattoo, 2008). There is no study thus far, according to our knowledge, which examines the effect of national vs. international standards on innovation. Existing empirical studies focus on the impact of standards on economic growth (Blind et al., 2021; Blind and Jungmittag, 2008) and international trade (Chen and Mattoo, 2008; Raballand and Aldaz-Carroll, 2005; P. Swann, 2010a) rather than innovation.

Early literature on national standards advocated that they would have a positive impact on trade and competitiveness (Moenius, 2004; Swann et al., 1996). For example, the first national standards provided guidance to companies, e.g. how to test (methods) but also how compare test results (measurements) of their products, such as LED lighting, solar modules or chemical residuals in an export crop. While common national standards created national markets and codified national technological knowledge in the past, which had irrefutably a positive impact on R&D and patenting incentives, we argue that they have a more restrictive influence in a world dominated by transnational production networks and global value chains. As national regulation, private regulation comes with compliance costs and multiple idiosyncratic national standards cascade compliance costs (Baldwin, 2000; Chen and Mattoo, 2008; P. Swann, 2010a). Melitz (2003) introduced the idea of fixed costs of exporting, which are significantly driven by technical regulations and standards. For example, firm surveys (Chen et al., 2006, 2008; Chen and Novy, 2012) among exporters in developing countries found compliance costs with (inter-)national standards to be the first non-tariff barrier to trade. The compliance costs associated with standards originate from product tests, inspections, audits and third-party certification necessary to demonstrate compliance with standards (see Castka et al., 2023). While both national and international standards come, in principle, with compliance costs, international standards reduce the costs of commercialising an innovative product in multiple markets. Mutual recognition of national or harmonisation towards one common international standard implies compliance costs occur only once and transaction costs decrease (Raballand and Aldaz-Carroll, 2005). For example, Schmidt and Steingress (2019) find that the introduction of harmonized standards increase trade through a larger sales volume of existing exporters and more entry. Chen and Mattoo (2008) show that regionally harmonized standards increases trade among member countries but reduces exports to the rest of the world.

While national standards reduce, international standards increase the size of markets with common rules for homogenous products. Larger markets, in turn, increase the potential return from commercialising an innovative product in multiple countries and thus increase the incentive to invest in R&D and/or patent (Aghion et al., 2018a, b; Blind, 2017). Given low tariffs and low transportation costs, mutual international standards create cross-border markets for homogenous goods and intensify international competition between multinational corporations, but also across local suppliers (Schmidt and Steingress, 2019). For example, (Guasch et al., 2007) illustrate how multinational corporations (in buyer-driven global value chains) can choose from a pool of national suppliers. What is more, international standards build the "common foundation upon which innovation technology" is developed (Ho and O'Sullivan, 2018) and technological development expands (Tassey, 2017). This technological focus also enables firms to benefit from economies of scale linked to mass production (Blind, 2017; Tassey, 2017). Consequently, firms or countries that engage in national standardisation risk to get locked into domestic technologies with high switching costs and a potential negative equilibrium where politicians maintain protection of under-performing firms in exchange for political support (Arthur, 1990; Baldwin, 2000; David, 1985; Tassey, 2017). Once agreed upon an international standard, competition takes place on a level playing field. For example, evidence from firm surveys and expert interviews suggest that the main motivation to join standardization committees is to find and influence common rules for interoperability, compatibility and common terminology to foster the dissemination of emerging technology (Blind and Gauch, 2009; Blind and Mangelsdorf, 2016). What is more, international standards provide certainty and credibility with foreign users, in particular in the early stages of commercialisation of innovative products (Blind, 2016; Blind et al., 2018a,b; Ganslandt and Markusen, 2001; Swann, 2010b). For example, compliance with international quality standards may lend the necessary credibility to new Indian producers of solar modules to export their products to Canada or Senegal in the light of fierce, established and reputed competition from Chinese producers (Ho and O'Sullivan, 2018).

To subsume, we argue that international standards create additional incentives to invest in R&D and file patents as they increase the market size to commercialize, build the basis for and spur incremental and radical innovation, and decrease the per unit costs of commercialising an innovative product in various countries.

Hypothesis 3. National standards correlate negatively with expenditures on R&D.

Hypothesis 4. International standards correlate positively with expenditures on R&D.

Hypothesis 5. National standards correlate negatively with the number of patent applications.

Hypothesis 6. International standards correlate positively the number of patent applications.

3. Empirical strategy

Empirically, it is indeed quite hard to evaluate the interplay between regulation and standards on the one hand and innovation on the other hand given regulation and standards are not uniform. The true effect of each single regulation and standard depends on the specific type of regulation/standard, its nature (e.g., safety vs. labour), the area (e.g., product markets vs. utilities), the character (e.g., restrictive vs. permissive, technology-agnostic vs. technology-prescriptive), the economic sector (e.g. fisheries vs. robotics) and the implementation of the regulation or standard. Litina et al. (2021), for example, conclude in a very recent paper that the extensive evidence in the empirical literature on the effects of Product Market Regulation is inconclusive. Given regulations and standards are not uniform, their impact also is not uniform – in other words, some regulation or standard may foster innovation and another stifle it – in this paper, we focus on the overall, aggregate single positive or negative interplay between different regulations and standards on the one hand and innovation on the other hand across countries and years.

3.1. Data

Table 1 presents the sample of observed countries and years. The panel contains all OECD countries except Chile, Iceland, Ireland, Luxembourg, New Zealand, and Slovakia. The years included in the panel are 1998, 2003, 2008, 2013 and 2018 as the OECD publishes the Product Market regulation index every five years. The Product Market regulation index has been used as a proxy for regulation in various

Table 1
Panel structure.

Country						Year
Australia	Denmark	Greece	Netherlands	Spain	United States	1998
Austria	Estonia	Hungary	Norway	Sweden		2003
Belgium	Finland	Italy	Poland	Switzerland		2008
Canada	France	Japan	Portugal	Turkey		2013
Czech Republic	Germany	Korea	Slovenia	United Kingdom		2018

earlier studies (Amable et al., 2010, 2016; Conway et al., 2005; Litina et al., 2021; Nicoletti and Scarpetta, 2003). Note that the data for 2018 is only available for the two dependent variables: number of PCT patents and total R&D expenditure in percentage of the GDP given the OECD has changed the methodology for calculating the PMR index, which makes over time comparison not possible post 2013.

Table 2 provides an overview of all variables and data sources. We retrieve the standards data from the Perinorm database for the majority of the countries in the panel. For Australia, Estonia, Finland, Greece, Korea, Portugal, Slovenia, and Hungary, we received the data directly from the national standardization bodies. The data about GDP is measured in constant US Dollars in 2010, on R&D expenditure and exports in the percentage of the GDP and is retrieved from the World Banks's World Development Indicators. The data for the portion of the population in tertiary education comes from the International Labour Organization (ILO) Key Indicators of the Labour Market database.

Table 2
Variables and data sources.

Category	VarName	Indicator	Data Source	Link
Dependent Variable	*patent*	Number of patent applications	OECD Main Science and Technology Indicators	OECD[3]
	rdi	R&D expenditure as percentage of GDP	World Bank Development Indicators	WB
Explanatory Variables	*nstd*	Stock of national standards	Perinorm database/ National Standardization Bodies	Beuth/ DIN
	istd	Stock of international standards	Perinorm database/ National Standardization Bodies	
	pmri	Product Market Regulation Index	OECD Public Sector, Taxation and Market Regulation database	OECD
Control Variables	*gdp*	GDP as measured in constant 2010 US Dollars	World Bank Development Indicators	WB
	rdi	R&D expenditure as percentage of GDP	World Bank Development Indicators	
	exppercgdp	Exports as percentage of GDP	World Bank Development Indicators	
	pop	Population	World Bank Development Indicators	
	terteduc	Percentage of population with tertiary education	ILO Key Indicators of the Labour Market	ILO

Table 3 presents summary statistics for the variables used for the analysis. We measure innovation input as country-level total gross R&D expenditure[4] and innovation output as the number of patent applications filed under the Patent Cooperation Treaty in year t. We choose this data because they present the broadest available and comparable patent figures in terms of quality requirements for such a large group of countries (for a recent discussion and advantages of use of PCT patents, see (Schmoch and Gehrke, 2022)). To proxy regulation, we use the OECD product market regulation indicator (Koske et al., 2015). The indicator measures the stringency of product market regulation based on questionnaires completed by member states in five year intervals. The indicator ranges from 0 to 6 with 0 representing no regulation and 6 the highest amount of regulation.

The variables *nstd* and *istd* measure the stock of valid national and international standards in a country in year t, which equals the number of all published minus all withdrawn standards. A standard is national if issued by a national standardization body and only adopted in this one country. A standard is international if published by an international standardization or by a national body and later adopted on the international level.[5]

We imputed missing values for a 12 observations (see Table "Imputation for R&D and patents" in the appendix). The values for certain countries were missing for the specific year t, but were available for t±one or two years. In these cases, we used the value of the year that was closest to t or, if several values in neighboring years were available, we took an average. Given national levels of regulations and standards do not change abruptly in general, imputation as illustrated, seems reasonable.

3.2. Model

We model both the interplay between rule-making and innovation input (R&D as % of GDP) and innovation output (number of PCT treaty patents). To model R&D as % of GDP, based on various tests that one can find in the appendix, we opt for a random effects model with robust, clustered standard errors to account for heteroscedasticity and autocorrelation. A Hausman test and a Breusch-Pagan Lagrange multiplier test suggest a random effect model rather than a fixed effect or a simple OLS model is appropriate (see the robustness check section for model estimates with the fixed effect model). Joint significance tests also suggest not to include year dummies. Note that as we control for country fixed effects, the variation comes from changes within countries over time (see appendix for illustration of variation in R&D between and

[3] We use the patents filed under the Patent Co-operation Treaty (PCT), at international phase, that designate the EPO. See https://stats.oecd.org/Index.aspx?DataSetCode=PATS_COOP.

[4] The R&D expenditure data provides information about total R&D expenditure, including private and public expenditure. We would have preferred business R&D expenditure only but the OECD Science and Technology indicators data base provides no data for 1998 and 2003 for about one third of the countries in our sample.

[5] There is a special situation for member States of the European Union (EU). The EU has its own supranational standardization bodies. The EU standardization system requires all Member States to adopt EU standards as national standards within their jurisdictions. Therefore, we count EU standards as national standards for all EU Member States, while counting them as international standards for all other countries.

Table 3
Summary statistics.

VarName	Unit	Obs	Mean	SD	Min	Median	Max
patents	count	130	5096.4	10790.3	5	1325.5	58,933
r&d	% in gdp	130	1.9	0.9	0.4	1.8	4.6
nstd	count	104	14499.9	9969.2	158	13383.5	50,837
istd	count	104	6526.7	5905.1	1	5701	30,330
pmri	score 1-6	100	1.8	0.5	0.9	1.6	3.3
gdp	billion	104	1535.9	2804.8	12.9	500.1	15853.8
terteduc	% population	104	27.3	9.4	8.3	28.6	51
exppercgdp	% exp/gdp	104	40.7	19.3	9	38.4	88

within countries over time). Hence, we define the first simplified model specification to estimate *r&d* similar to Blind (2012) as following:

$$r\&d_{it} = \alpha + \beta_1 pmri_{it} + \beta_2 \ln(nstd)_{it} + \beta_3 \ln(istd)_{it} + \beta_4 controls_{it} + u_{it} + \varepsilon_{it} \tag{1}$$

where indices *i* and *t* stand for the sample countries and years, *r&d* is the winsorized percentage of gross national R&D expenditure in GDP, α is a constant, *pmri* refers to the product market regulation index, the number of national and international standards *nstd* and *istd* are log-transformed, *controls* is a vector of the control variables *gdp, terteduc, pop,* and *exppercgdp*, u_{it} is the between entity error and ε_{it} is the within-entity error.

For the analysis of patents, we opt for a two-way Poisson panel fixed effect model. Although the dependent variable patent count is over-dispersed, we opt for a Poisson rather than a negative binomial model. The reasons are the following. Firstly, panel negative binomial model cannot account for serial correlation (which is present as we document in the appendix). Secondly, efficiency gains relative to Poisson regression are likely inexistent or small in the case of fixed effects (Cameron and Trivedi, 2013). Finally, leading statisticians suggest the panel fixed effect negative binomial model is flawed and advice to use Poisson panel fixed effects (Guimarães, 2008; Wooldridge, 1999).[6] Therefore, as in model 1, the variation comes from within country changes over time (and not between countries). In contrast, for causal interpretation of the results, assumption (1) from model 1 is sufficient given country specific effects are differentiated out (and thus also not estimable).

$$patents_{it} = P\left(\alpha_i + \beta_1 pmri_{it} + \beta_2 \ln(nstd)_{it} + \beta_3 \ln(istd)_{it} + \beta_4 controls_{it} + \varepsilon_{it}\right) \tag{2}$$

where *patents* is the annual number of PCT patents, *P* stands for the Poisson transformation and all variables but *pmri*, *terteduc* and *exppercgdp* are in natural logarithms. The model contains the intercept α and a standard error term ε. The *controls* are the same as for model 1 but also include a year dummy (given a test for joint significance rejects the null hypothesis) and R&D expenditure in % of GDP.

3.3. Results

Firstly, we present the results for innovation input measured as gross national R&D expenditures in percent of countries' GDP, secondly, the results for innovation output measured as the number of annual patents per country.

3.3.1. Standards, regulation and R&D (innovation input)

Table 4 shows the main results of the regression analysis on R&D. We found that, on average, international standards positively affect a country's R&D spending in the short term (the year of and the year after issuance). Interestingly, this correlation fades five years post-issuance. This pattern may stem from the collaborative nature of setting international standards, as opposed to the top-down approach of government regulations.

To illustrate, a 1% increase in international standards (about 65

Table 4
Main regression results for R&D expenditure.

VARIABLES	(1) mean R&D expenditure	(2) R&D exp. in t	(3) R&D exp. in t	(4) R&D exp. in t+1	(5) R&D exp. in t
gross R&D expenditure in % of GDP	1.9 [.9]				
Log national standards		.12 (.078)	.045 (.054)	−.000038 (.00073)	
Log international standards		.11** (.057)	.11*** (.038)	.0013** (.00059)	
Product market regulation index		−.31*** (.11)	.22 (.2)	.0023 (.0019)	
Log GDP			.26*** (.087)	.0033*** (.00077)	
% population with tertiary education			.026** (.012)	.00022* (.00011)	
Export in % of GDP			.017*** (.0041)	.00018*** (.000041)	
Log of lagged national standards					−.05 (.12)
Log of lagged international standards					.1 (.09)
Lagged PMR index					−.075 (.25)
Log of lagged GDP					.35*** (.1)
Lagged % of population with tertiary education					.0026 (.014)
Lagged export in % of GDP					.014** (.005)
Constant		.4 (1.1)	−8.1*** (2.9)	−.099*** (.028)	−8.3** (3.8)
Observations	130	100	100	100	100
Number of Country		26	26	26	26

Note: Robust, clustered standards errors are in parentheses and starts indicate statistical significance as follows:
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. All estimations are based on panel linear fixed effects models. Column (1) provides the mean and standard deviation in squared brackets of R&D across countries and over the sample period. Column (2) corresponds to equation (1) without control variables. Column (3) adds control variables and is equivalent to equation (1). Column (4) corresponds to equation (1) but with R&D in year t+1. Column (5) corresponds to equation (1) but with lagged explanatory variables in t-1 (=5 calendar years earlier).

[6] See Jeffrey Wooldridge and Joao Santos Silva, for example in this Statalist blogpost (last accessed February 7th 2022) on November 4th 2020: "I'd now go as far as stating FE NBREG should never be used. It's a weird model and has no know robustness properties."

standards based on the sample mean) is linked to 0.0011 percentage points in R&D spending relative to GDP in the same year. In the following year, the relation diminishes to 0.000013 percentage points. The median change in international standards over the time period is 31.3% or ~2042 international standards, reflecting the ongoing globalisation. To put this into perspective, the median number of international standards in 1998 was 3307. A 31.3% increase in international standards correlates with a 0.03 percentage points increase in R&D spending relative to GDP, equivalent to an 1.5% increase in mean R&D expenditure over GDP. In absolute terms, 0.0011 (0.03) percentage points are equivalent to 550 million (14.9 billion) USD. Accordingly, a 1% change in countries' stock of international standards (65 standards) correlates with increased R&D expenditures by approximately 550 million while the actual median 5-year increase in international standards (2042 standards) correlates with increased gross national R&D expenditures by approximately 14.9 billion USD. In comparison, the annual budget of the US Defense Advanced Research Projects Agency (DARPA) consists of ~3.5 billion USD in 2022, annual business expenditure on R&D in Germany was roughly 9.3 billion, 1.1 billion in the Netherlands and 270 million in Estonia in 2018.

Note that neither national standards nor regulation are significantly correlated with gross national R&D expenditures (once control variables are added). This is particularly surprising in so far as the current literature suggest both standards and de-regulation should be positively correlated with R&D expenditures. Indeed, the results suggest that national standards lose their attractiveness in an increasingly globalised world economy. At best, we can not conclude that they are negatively associated with gross national R&D expenditure but the results clearly oppose earlier research (Moenius, 2006; Swann et al., 1996) and suggest the changing structure of the world economy also converted the way how national vs. international standards affect incentives to invest in R&D. Regarding regulation, the key argument against regulation and in favour of de-regulation is that de-regulation frees up resources for businesses to invest in innovation – however, our results reveal that the implicit assumption businesses would use resources freed up resources from lower regulatory compliance costs to invest in R&D does not hold. While early research has shown (some type of) regulation forces businesses to invest in regulatory compliance (Chakraborty and Chatterjee, 2017; Porter and Van der Linde, 1995; Song and Chen, 2010), de-regulating provides businesses with resources that end up somewhere but not in R&D expenditure.

3.3.2. *Standards, regulation and patenting (innovation output)*

In the following Table 5 provides regression results for patents. Indeed, the results suggest an interesting pattern. Firstly, national and international standards are different.

National standards are significantly negative correlated with PCT patents in the same (at the 10% level) and the following year (at the 5% level). A one (ten) percent increase in national standards is associated with a 0.41% (4.1%) decrease in the number of PCT patents filed both in the same and the following year. Over the sample period, countries had a median (average) growth rate in national standards of 22% (48%). A 22% (48%) increase in national standards is associated with a 9% (19 %) decrease in patents, corresponding to 119 (1001) patents over the sample period. In comparison, 119 PCT patents are as much as a country like Slovenia or Greece filed in total in 2018, while 1001 PCT patents are roughly equivalent to the amount an economy like Turkey, Denmark or Finland filed in 2018.

International standards are significantly positively correlated with PCT patents both in the same and the following year at the 5% level. A one (ten) percent increase in the former is associated with a 0.35% (3.5%) increase in PCT patents. The average (median) percent increase in international standards promoted 6132 (145) additional PCT patents. 6132 PCT patents are almost double the PCT patents filed in 2018 in Italy or the Netherlands, while 145 PCT patents are about equivalent to the output of countries like Slovenia or Greece as mentioned above.

Table 5
Main regression table for PCT patent count.

VARIABLES	(1)	(2)	(3)	(4)	(5)
	Patents mean	Patents in t	Patents in t	Patents in t+1	Patents in t
PCT patents	5096 [10,790]				
Log national standards		−.54 (.38)	−.41* (.22)	−.41** (.21)	
Log international standards		.83*** (.19)	.35** (.15)	.35** (.16)	
Product market regulation index		−.61*** (.16)	−.28 (.2)	−.40** (.19)	
Log GDP			−.21 (1.1)	−.21 (.97)	
gross R&D expenditure in % of GDP			.47*** (.15)	.43*** (.15)	
% population with tertiary education			.016 (.013)	.019 (.012)	
Export in % of GDP			−.013 (.0097)	−.01 (.01)	
year = 2003			.22 (.15)	.052 (.13)	
year = 2008			.32 (.26)	.039 (.23)	.035 (.085)
year = 2013			.47 (.3)	.14 (.26)	.23* (.12)
Log of lagged national standards					−.15 (.13)
Log of lagged international standards					.17* (.096)
Lagged PMR index					−.088 (.12)
Log of lagged GDP					−.29 (.58)
Lagged gross R&D expenditure in % of GDP					.38*** (.12)
Lagged % of population with tertiary education					.014** (.007)
Lagged export in % of GDP					−.012* (.006)
year = 2018					.18 (.15)
Observations	130	100	100	100	100
Number of Country		26	26	26	26

Note: Robust, clustered standard errors in parentheses and stars indicate the significance level as following:
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Column (1) provides the mean patent count with standard deviation in squatted brackets across sample countries between 1998 and 2018. Column (2) provides panel Poisson regression estimates of patent count on the major explanatory variables all in year t and in country i. Column (3) is identical to column (2) but also includes control variables and therefore represents equation (2). Column (4) shows panel Poisson regression estimates of patent count in calendar year t+1 and all explanatory variables in t for countries i. Column (5) shows panel Poisson regression estimates of patent count in year t and explanatory variables in t-5 (lagged = 5 calendar years earlier). All regressions are estimated with fixed effects.

We suggest that the varying impacts of national and international standards stem from the higher costs of commercialising patents in markets with unique national standards, as opposed to the larger returns and economies of scale achieved in markets with international standards.

Finally, we turn to regulation. Re-call from the previous section that de-regulation is not significantly correlated with R&D expenditures over the sample period according to model estimates. Yet, a one-unit decrease in regulation was associated with a 33%[7] increase in the number of PCT patents filed. Regulation decreased on median (average) by 0.21 (0.26) units. Accordingly, such decreases are associated with a 9% (11%) decrease in the number of PCT patents filed. This is equivalent to 120 (568) PCT patents based on the sample median (average) PCT patent count over the sample period. Finally, in comparison to standards, the interplay with regulation seems to occur with a certain delay given that the estimates for regulation in column (3) are not significant.

At first thought, the regression results are clearly puzzling: although de-regulation is not correlated with investment in R&D (input), de-regulation is positively associated with patenting (innovation output). Based on recent literature (Boldrin and Levine, 2013; Cohen et al., 2002; Gilbert and Newbery, 1982; Torrisi et al., 2016; Walsh et al., 2016), we argue that de-regulation correlates with patenting to replace lost protection from low competition based on regulation with protection based on patent fences. Hence, we interpret the model estimates as suggestive that resources freed-up by de-regulation are invested elsewhere but not in R&D; instead patenting volumes may increase as established firms seek to rebuild new protecting fences from de-regulation induced competition – fences based on patents rather than regulation.

Finally, Table 6 summarizes the findings and provides an overview including a comparison of the magnitude of the coefficients of national standards, international standards and regulation on R&D and PCT patents. Table 6 suggests that the big story in economic rule-making and innovation in the recent period of globalisation is about international standards. International standards are both positively associated with R&D expenditure and PCT patents, and grew at a pace and magnitude beyond what we observed for de-regulation and national standards. Indeed, the model estimates suggest that for the median sample growth rate international standards is associated with an increase of 14.9 billion USD in R&D expenditures and 145 additional PCT patents. In contrast, de-regulation is not positively correlated with R&D expenditure, but only increased patenting, which is at first puzzling. From an optimistic perspective, one could reason de-regulation increases competition, which forces established firms to increase their innovation efficiency (increase the number of patents at unchanged R&D effort). From a more pessimistic point of view, one may assume that de-regulation induced competition lead established firms to try to substitute lost protection based on regulation with patent fences. As in the case of US tax reform, at least some firms may have invested freed-up resources while other may spend on dividends, bonuses and share paybacks (Gale and Haldeman, 2021; Hanlon et al., 2019; Olson, 2019). At least, these results call into question recent whether prominent calls and the narrative of de-regulation being a driver for innovation can be uphold. Based on our estimates, scholars should revisit and re-evaluated it. Finally, national standards, which existing research argued would promote innovation, have become barriers to (international) innovation in the recent period of globalisation. While national standards are not associated with R&D expenditure, they are negatively correlated with PCT patents. This suggests national standards localize economies, which leads to a reduction of international patenting efforts and may fuel national withdrawals from the world economy that are unlikely to promote countries long-term technological development. This may not be true for global lead and standard-setting markets like the US, China or Japan as indicated in the table “Robustness check 7” in the appendix.

Table 6
Overview of hypotheses and regression results.

	Regulation	Natl. Standards	Intl. Standards
R&D			
Hypothesis	+	–	+
Coefficient/Significance	.22	.045	.11***
Magnitude for median change over time period in explanatory variable in terms of absolute R&D in USD	–	–	540 million USD
PCT Patents			
Hypothesis	–	–	+
Coefficient/Significance	−.40*	−.41**	.35**
Magnitude for median change over time period in explanatory variable in terms of number of PCT patents	120	119	145

Note: All results are based on a change of the average magnitude observed among sample countries over the sample period in the respective explanatory variable. Dependent and explanatory variables are in the same time period year = t with the exception of the correlations of de-regulation on patents (which is based on patents in t+1) and including control variables. Coefficients are retrieved from Tables 4 and 5 columns (3). Hypotheses were formulated in the literature review. Calculations for the magnitude can be found in sections 3.3.1. for R&D and 3.3.2. for patents. Robust, clustered standard errors in parentheses and stars indicate the significance level as following: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

3.3.3. Robustness checks

We conduct three robustness checks for both R&D and PCT patent estimations to examine the sensitivity of the results. First, we estimate a two-way fixed effects model instead of a random effects model without year dummies for R&D and a random effects model for PCT patents. Tables “robustness check 1” and “robustness check 6” in the appendix suggest that there are no differences in terms of statistical significance or direction of the three major explanatory variables in both models. Second, we checked whether the results for R&D and PCT patents are sensitive to any changes in the specific sample composition of countries. For this purpose, we conducted leave-one-out estimations leaving out each country once and estimating the model without the observations for this country. Table “robustness check 2” in the appendix suggests that the model estimates for R&D are not sensitive to leaving out any country. In contrast, table “robustness check 7” in the appendix illustrates that the model estimates for PCT patents are partially sensitive for sample composition: while the direction of the explanatory variables is always the same, the negative correlation with national standards turns insignificant if one removes Finland or Japan from the sample. Figs. 6 and 11 in the appendix “further descriptive statistics” illustrate that while Finland does not seem to be an outlier in any dimension, Japan is a somewhat special case it combines relatively low levels of both national and international standards with a high number of PCT patents. This may explain why it is important to account for Japan for the model results. In addition, the positive significant correlation with international standards turns slightly insignificant when removing the United States; note, however, that the correlation is significant at least at the 10% level and might thus only express random noise rather than actually idiosyncratic dependency of the interplay on the presence of the United States. Finally, we also examined the models’ sensitivity to the model specification. Table “robustness checks 3” in the appendix illustrates that neither significance nor direction of the major explanatory variables are sensitive to leaving out any variable in the case of the R&D estimations. The same is also true for PCT patents with the exception of national and international standards sensitivity to each other’s presence. In fact, table “robustness checks 6” in the appendix illustrates that the significance of the correlation of international and national standards with PCT patents depends on their respective presence in the model; in other words, once we do not control for the level of national standards, the correlation with international standards becomes insignificant and vice-versa. Given both type of standards have opposite correlations with innovation input and output, this suggests it is crucial to account for

[7] Calculus: $(e^{-.4} - 1) * 100$.

national or international character of standards in a globalised world economy.

4. Conclusion

This paper is the first to empirically explore how standards and regulation interact with innovation, focusing on how globalization, deregulation, and the internationalization of rule-making influence R&D investment and international patent filings. The findings provide interesting insights. First and foremost, international standards correlate with both R&D expenditure and patenting, outperforming national standards and regulation. The model estimates suggest that the increase in international standards correlated with an additional 150–450 million USD invested and more than six thousand PCT patent applications between 1998 and 2018 among 26 high-income countries. In contrast, national standards are uncorrelated with R&D expenditure and even negatively associated with PCT patents. Earlier research, which was realised when global-value-chains only started to operate and focused on single countries at the top of the technology frontier (Moenius, 2006; Swann et al., 1996), viewed national standards as competitive advantages. Our results suggest that national standards – in a globalised economy – rather restrict countries innovation.

Secondly, we contribute to the perpetual debate of the interplay between (de-) regulation and innovation, which we link to the debate about the merits and pitfalls of patents. We show that de-regulation is positively correlated with patenting while it is uncorrelated with R&D expenditures. This raises the following puzzle: how could innovation output increase while innovation effort or input was left unchanged? We argue that de-regulation induces competition, and competition pushes firms to pre-emptively and strategically patent to resurrect protection lost due to de-regulation with patent fences. Had competition simply motivated firms to make more effort, one would have expected to see R&D increase in response to de-regulation too. While we cannot prove this argument empirically, we consider the results call for future research to investigate whether this hypothesis could answer the above-mentioned puzzle. In particular, it would be interesting to evaluate whether de-regulation induced patents are potentially of lower-quality and/or sleeping patents and how firms use the freed-up resources from lower administrative burden (e.g. as dividends). In general, we believe it is a promising avenue for future research to seek to identify exogenous variation in regulation, national or international standards to corroborate the macroeconomic results and interpretation presented in this paper.

Considering the study's findings, policy recommendations should focus on balancing the benefits of globalization and onshoring, while fostering innovation. Governments should consider supporting international standards that promote global trade and innovation, rather than reinforcing national standards that may hinder competitiveness in the global market. Additionally, while the trend towards deglobalization and onshoring is emerging, policies should ensure that these shifts do not stifle innovation. This could involve linking incentives for R&D with work in international standardization committees and maintaining open channels for international collaboration in research and standardization. These strategies will be crucial in ensuring that onshoring does not compromise firms' incentives to commercialize innovation internationally.

While we believe the presented approach is the best possible given current data availability, there are several limitations. Firstly, the panel regression approach only allows for causal interpretation of our finding under the relatively strong assumption that there are no other variables than those included in the model that co-vary with standards/regulation and the R&D and patents. The estimation strategy accounts for between country difference in sticky (time-invariant) factors, e.g. institutions, economic structures, social capital, broader economic and technological development of a country etc., but is sensitive to unobserved within country changes not captured by the variables included in the model. The reassuring part is that it is not immediately obvious what specific variables that could be given include the main variables used in cross-country studies related to innovation are included in the model. Given the aggregated level of analysis, one should read the results as net changes, which average out specific sector, firm, and policy-specific trends, e.g., related to the specific design or stringency of a regulation. The estimations should therefore be read as descriptive associations and general trends, and not causal effect, which would require an identification strategy, like natural experiments or appropriate instruments.

A further limitation relates to the sample. The results apply to a specific sample of countries that are not representative of the population of countries that participate in the globalising economy. The role of regulation and standards may be different for a different profile of countries, such as emerging markets or developing countries. For example, higher uncertainty in developing and emerging economies may alter the function of regulation and standards (Blind et al., 2017). More data would be urgently needed as we know that modelling innovation in a globalised economy only based on OECD countries does not provide a complete picture.

Moreover, both dependent and independent variables are imperfect proxies. The measurement of innovation remains a topic of debate. R&D and patents are the most common measures but have their shortcomings. The level of analysis (country) and the resulting level of aggregation of regulation and standards leads to crude results. The existing data only allows to consider "regulation" as a homogenous indicator even though regulation can take many different shapes. The PMR index from the OECD is one of the few available measurements for regulation (see Quignon, 2022 for an alternative approach); yet, it remains an imperfect measurement. We urgently need better and more disaggregated data about regulation that allows looking at different sectors as well as other types of regulation across different countries and over time. Recent approaches to create regulation typologies (McEntaggart et al., 2020) are certainly a step in the right direction but need matching data collection effort on the international level. Finally, the stock of national and international standards is certainly a first indicator. However, what one would be interested in is the use, or in other words, diffusion of the respective standard across an economy. Furthermore, regulation and standards are not necessarily independent, but in particular in the Member States of the European Union complementary. However, regressions including interaction effects did not generate robust results.

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CRediT authorship contribution statement

Knut Blind: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Florian Münch:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2024.141202.

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