No double standards: quantifying the impact of standard harmonization on trade

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Abstract

This paper quantifies a novel channel that contributes to greater trade integration: the release of harmonized, voluntary product standards. Standards define product characteristics that ensure compatibility, quality and consistency. Harmonized standards unify these characteristics across countries and reduce country-specific adaption costs. We create a novel database on cross-country standards and show that harmonized standards have contributed up to 13% of the growth in global trade. We build a heterogeneous firm model where harmonized standards generate scale effects and induce firms to adopt the standard. Firm-level evidence shows that only the largest firms in the top range of the size-distribution increase their export sales. These firms benefit from higher demand, charge higher prices and sell larger volumes.

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1 Introduction

Product standards are omnipresent and affect production processes in virtually all industries (ISO, 2016). Prominent examples are A4 paper format, electrical plugs or 4G mobile phone standards. Over the last decades, international standard-setting organizations (SSOs) have dominated the standard development process by releasing harmonized voluntary product standards that adopters can choose to use in their production processes. This silent form of trade integration, which is not necessarily the result of government trade policy, shapes the way firms produce and sell their output abroad.

The benefits of standards have already been pointed out as early as Kindleberger (1983). Through standardization, firms can overcome information asymmetries (Leland, 1979), increase product quality (Ronnen, 1991), ensure interoperability and take advantage of positive network effects (Katz and Shapiro, 1985; Farrell and Saloner, 1985). For example, quality and technical standards enable firms to organize production processes more effectively and increase product quality (Verhoogen, 2008). They allow consumers to better assess product attributes through certification or labeling. Compatibility standards (think of screw threads or mobile phone standards) allow for network effects and economies of scale, thus facilitating supply chains and mass production.

If standards are specific to each country, high investment costs prevent firms, and ultimately consumers, from reaping the benefits of standardization, which is especially important in a globalized world where products are sold internationally. When adapting products and processes to a specific standard in each country, producers must design standard-compatible blueprints, retool machines and potentially reorganize plants. Harmonized standard releases, i.e. the explicit accreditation of the same standard by several national SSOs, unify product characteristics across countries and reduce country-specific investment costs. Firms no longer need to change their production process when selling to a different country, resulting in more firms choosing to adopt the standard. The uniformity of product characteristics across countries may also increase the marketability of products. For example, producers using 4G mobile phone standards ensure that their products not only work in many countries but are also compatible with applications such as mobile web access, IP telephony and video conferencing.

The main contribution of this paper is to highlight the release of harmonized, voluntary standards as a novel channel of higher trade integration and to quantify its effect on international trade. By shifting the focus from regulatory to voluntary standards and their harmonization, we depart from the trade literature that views product standards through a regulatory lens. Voluntary standards span beyond the health, safety and environmental aspects usually covered by regulatory standards. Our database includes more than one million standards, of which almost half are harmonized, thereby largely outnumbering the number of regulatory standards commonly found in databases on non-tariff barriers.[1] Voluntary standards are developed by standard-setting organizations (SSOs), where industry experts work together to agree on the formal specification of

[1]Over 1995–2014, regulatory standards notified to the WTO cover close to 20,000 standard notifications.

product characteristics. Their release differs from trade policy efforts where governments mandate product characteristics through regulatory standards and prohibit non-compliant firms from selling their products.[2] Voluntary standards give firms the option to change their production structure. As our analysis shows below, this difference has important implications for the firm-size distribution.

To construct our novel bilateral product-level database, we track the release and accreditation of foreign and international standards for each SSO within the Searle Center Database on Technology Standards, Industry Consortia and Innovation (Baron and Spulber, 2018). We define standard harmonization as the decision of a national SSO to accredit a standard that is also released in another country. To assign standard documents to products in the trade data, we use a newly developed concordance table between the International Classification for Standards (ICS) and the Harmonized System (HS). Our final sample contains bilateral product-level trade flows and standard releases for 20 industrialized countries and several major emerging economies for the period 1995–2014.

To quantify the effect of standard harmonization on international trade, we follow a difference-in-difference approach. Our results show that, on average, the introduction of harmonized standards increases product-level trade flows by 0.59%. This marginal effect is amplified by the fact that every year harmonized standards are released in more than 40% of all bilateral product-level trade flow pairs. Overall, we estimate the average contribution to global trade growth to be 0.30 percentage points per year. This increase represents five times the contribution of tariff reductions over our sample period.

We provide evidence that the assumptions of our difference-in-difference approach are satisfied and address potential endogeneity concerns. First, we show that there are no significant differences in pre-trends between harmonized and non-harmonized products. Second, we provide evidence that our results are not driven by the fact that harmonized standards may be primarily released in product categories with larger trade flows or higher growth rates. Third, we mitigate the endogeneity concern that firms' participation in SSOs' activities determine the release of harmonized standards. To this end, we take advantage of the supranational character of so-called European Standards. Fourth, we instrument country-specific harmonization events by accreditations of neighboring countries. The estimates of the instrumental variables approach are not significantly different from our baseline OLS estimates, suggesting that the latter estimates are causal.

The voluntary nature of product standards implies that our product-level estimate depends on the number of firms that choose to adopt the standard and their change in export sales. To build intuition for this firm-selection effect, we construct a multi-country model with heterogeneous firms and endogenous standard adoption, i.e. firms decide to produce a standardized or a non-standardized variety of a differentiated product. Product standards capture product attributes, such as quality, compatibility, safety or environmental aspects, which consumers value. Producing standardized varieties requires sunk investment

[2]Governments either agree to reference another countries' standards or international standards in their legislation and apply the same standard to both foreign and domestic products (national treatment), or they allow the sale of products under both the national and foreign standards (mutual recognition).

costs and potentially higher marginal costs.[3] The presence of sunk investment costs implies a selection effect where large high-productivity firms choose to produce in accordance with the standard, while small low-productivity firms decide to produce the non-standardized variety. Because of higher demand for standardized varieties, only those firms able to cover the investment costs increase their export sales. The release of a *harmonized* standard across countries enables more firms to reap the benefits of standardization because firms pay the sunk investment cost only once while receiving higher product demand in all countries that release the harmonized standard.

To quantify the selection effect and the heterogeneous responses across the firm-size distribution, we use firm-level data obtained from French custom declarations. A limitation is that the data do not allow us to identify the firms that choose to produce in accordance with the harmonized standard. For this reason, we exploit the predictions of the model and test whether the marginal effect of standard harmonization affects export participation and varies with firm size, trade costs as well as destination country characteristics. A decomposition of our baseline product-level specification into the extensive margin (number of exporters) and intensive margin (average export sales) shows that harmonized standards increase trade through higher average sales of existing exporters and has no significant effect on firm entry. When we split firms into size-bins according to their overall sales, only the largest exporters in the highest quartile experience positive and significant effects. Their export sales increase by 1.1%, while the effect is insignificant for remaining firms. High sunk investment costs imply that only few firms choose to invest in the standard and explain why the treatment effect at the firm-level is twice as large as at the product-level.

We further show that this size-dependent selection effect of harmonized standards increases with destination country size, lower bilateral trade costs and the number of countries releasing the harmonized standard. These heterogeneous effects are consistent with the model. Finally, we provide suggestive evidence of harmonized standards shifting demand towards standardized varieties. We find that the positive effects increase with the degree of product differentiation and are greater for standards whose purpose it is to signal quality or reduce information frictions.

Related literature The effect of releasing harmonized standards is similar to the mechanism described in the literature on technology and quality upgrading following trade policy shocks. Improved access to foreign markets through lower tariffs or an exchange rate depreciation generates scale effects and induces firms to upgrade their quality (Verhoogen, 2008) or technology (Lileeva and Trefler, 2010; Bustos, 2011). Another channel is the cost reduction of intermediate inputs through a reduction in import tariffs that leads to

[3]These features are consistent with recent models on product standards, such as Baldwin et al. (2000), Costinot (2008), Podhorsky (2013), Mei (2018) and Macedonia and Weinberger (2022). The sunk investment costs are similar to "compliance costs" in Maskus et al. (2005), "adaption costs" in Maur and Shepherd (2011) and Toulemonde (2013), "conversion costs" in Gandal and Shy (2001) and "setup costs" in Fischer and Serra (2000). Standards can increase consumer demand because they reduce distortions due to information frictions (Leland, 1979; Atkeson et al., 2014), increase quality (Ronnen, 1991) or create positive network externalities from more users (Katz and Shapiro, 1985; Farrell and Klemperer, 2007).

quality upgrading (Amiti and Khandelwal, 2013; Fan et al., 2015; Bas and Strauss-Kahn, 2015).[4] In comparison, this paper provides novel evidence of another trade shock that stimulates firm investment. By unifying product characteristics across countries, the release of harmonized voluntary standards induces firms to upgrade their products. Firms benefit from higher product demand and save on country-specific investment costs to adapt their products to the destination market, similar to the scenario considered by Arkolakis et al. (2021). Overall, our results suggest that these harmonization efforts are an important driver of global trade.

Related to the literature on trade policy uncertainty (e.g. Handley and Limão, 2017, and Steinberg, 2019), the release of harmonized voluntary product standards is also a non-regulatory trade policy shock. Handley and Limão (2017) show that absent any changes in regulatory trade policy (such as tariffs), the reduction in the likelihood of higher tariff rates can stimulate firm-entry investment today because of higher expected future revenues. One feature of voluntary product standards is that they can reduce uncertainty about product characteristics. The certification and labeling of products via standards can reduce costs for buyers to evaluate the product before purchase. To the extent that compliance with standards requires sunk investment costs, which is similar to the fixed costs of entry into foreign markets considered by Handley and Limão (2017), the implied firm selection effects are similar in the two models: large and high-productivity firms are more likely to invest.

The paper also relates to the empirical international trade literature on product standards. While regulatory product standards are usually thought of as trade barriers, the seminal contribution by Swann et al. (1996) shows that standards promote exports. Blind (2004) emphasizes the trade-enhancing effects of standardization through quality improvements and economies of scale.[5] Chen and Novy (2012) also show that standards are associated with lower bilateral trade costs. More recently, Fontagné et al. (2015) and Fernandes et al. (2019) analyze firm dynamics and show that restrictive regulatory standards have a detrimental impact on firm-level export sales and net entry, but less so for larger firms.[6] We add to this literature by pointing out the different selection effects on exporting for regulatory and voluntary standards and their implications on the firm-size distribution. While regulatory standards have been shown to mainly affect smaller exporters, the empirical evidence in this paper finds that voluntary standards increase predominantly the sales of the largest exporters.

Some papers analyze specifically the effect of cross-country standard harmonization on trade flows for certain regulations within a subset of industries or countries. Chen and Mattoo (2008) use information on EU/EFTA harmonization and mutual recognition agreements and find that trade flows increase between participating countries, but exports of

[4] Alternatively, firms may decide to invest in higher quality only after having learned about demand through experience in the foreign market (Rodrigue and Tan, 2019; Berman et al., 2019).

[5] See Swann (2010) for a literature review on the trade effects of standards.

[6] Interestingly, Macedonia and Weinberger (2022) show that raising the minimum quality level via regulatory standards can improve welfare, if the competition with low-quality firms prevents high-quality firms from producing at the efficient scale.

excluded countries can actually decrease. Disdier et al. (2015) also show that harmonization between Northern and Southern countries is associated with increasing trade flows and point out the trade-deflecting effect on South-South trade. Reyes (2011) shows that the harmonization of EU electronics standards led to an increase in the number of US firms exporting to the EU in that sector.

The increased referencing of product standards in trade agreements (Baldwin, 2011) has led to an increase in the number of papers that study the regulatory aspects of harmonizing product standards. For example, Mei (2018) studies the welfare effects of regulatory standards using a quantitative general-equilibrium model. He finds that countries increase their welfare by 1.4% when setting a harmonized standard that is common to all countries. Parenti and Vannoorenberghe (2022) study the decision to coordinate on common product standards within a trade agreement when countries have different regulatory preferences. If divergence in these preferences is small, countries gain from signing a trade agreement featuring standard harmonization. Maggi and Ossa (2020) analyze how the decision to sign such an agreement changes if regulators are subject to industry lobbying. Grossman et al. (2021) study optimal regulatory policies and tariffs within a trade agreement when countries differ in their preferences for horizontally differentiated products. They evaluate different scenarios and provide conditions under which cooperative tariffs and mutual recognition (i.e. the foreign country accepts the standard set by the home country) or fully harmonized standards (i.e. the standard is identical in the home and foreign country) lead to a globally efficient trade agreement.[7] This paper adds to this literature in two ways. First, we highlight the parallel effort of standard-setting organizations in achieving convergence on product characteristics through the release of common voluntary product standards. In the aforementioned papers governments mandate changes in the production structure through regulatory compliance. Second, our empirical estimates suggest that firm heterogeneity plays an important role when considering trade policies on product standards. The presence of sunk investment costs implies lower average costs for larger firms and puts smaller firms at a competitive disadvantage.

The rest of the paper is organized as follows. Section 2 describes the standard-setting process and Section 3 presents the theoretical framework that we use to derive the regression specification as well as some empirical implications. Section 4 explains the data and stylized facts on cross-country standard harmonization. Section 5 presents the main results before endogeneity concerns and robustness checks are addressed in Section 6. In Section 7, we present empirical evidence on some of the implications of the model while the last section concludes.

2 Background information on standard-setting

Standards are released by different standard-setting organizations (SSOs). An SSO can be organized at the national level (for example, the German Institute for Standardization,

[7]Our data does not allow us to identify mutual recognition. This would require knowing that the accreditation of a trading partner's standard was part of a mutual recognition procedure.

DIN, or the Standards Council of Canada, SCC), can be an international standard-setting body (such as the International Organization for Standardization, ISO) or an industry association (such as the Institute of Electrical and Electronics Engineers, IEEE). Many SSOs are non-profit, non-governmental organizations. SSOs elaborate standards in working groups and technical committees that are composed of industry experts. For example, within ISO, there are technical committees (TC) on a variety of issues such as screw threads (ISO/TC 1), cosmetics (ISO/TC 217) or blockchain technologies (ISO/TC 307). The experts in those committees participate and vote on the release of standards on behalf of private firms and non-governmental and governmental agencies (Spulber, 2019).

Over the last decades, the majority of standardization activity is organized at the international level. National SSOs increasingly release standards originally developed by international SSOs, thereby promoting the uniformity of technical and product specifications across countries. Indeed, the German Institute for Standardization (DIN) reports that today roughly 85% of its standard projects are of European or international origin.[8]

One can distinguish between several different types of standards. For example, quality standards describe the properties of a product or process (e.g. the composition of dental implants or ISO 9000 quality management). For the purpose of measuring, testing or certifying certain quality levels or product attributes, firms make use of conformity assessment standards (e.g. car safety crash tests or guidelines for personal data protection). To set a common ground among suppliers and users of a certain product, standards can be used to harmonize terminology (e.g. the definition of knitting techniques in the textile industry). In order to assure that components and parts can be produced by different suppliers and to operate network technologies, a large number of SSOs develop compatibility standards (e.g. screw threads or wifi technology) or technical standards (e.g. the QWERTY keyboard or the file format used for 3D printing).[9] A standard can be categorized into more than one of these types and the standards in our database actually often fulfill several of these purposes.

The standards released by SSOs are often called consensus standards. They are voluntary[10] but can become legally binding through government regulation. For example, standard IEC 331:1970 that deals with fire-resistant characteristics of electrical cables has been incorporated by reference into the U.S. Code of Federal Regulations. When a national SSO accredites an international standard, the standard remains voluntary in

[8]See https://www.din.de/en/about-standards/a-brief-introduction-to-standards.

[9]There exists no official categorization of the different standard types. See for example the discussion in Swann (2000). The standard ISO 22794:2007 describes materials to be used in dental implants and how to evaluate their performance. ISO 9000 is a standard family for quality management. ASME B1.1-2003 describes dimensions for screw threads used in the United States and Canada. IEEE 802.11 is the most well known wifi standard. ISO 7862:2004 defines test procedures for the evaluation of restraint systems in passenger cars that can be used in crash tests. BS 10012:2017 describes data protection guidelines for the management of personal information. INCITS 154-1988[S2009] describes the arrangement of the keys and the respective characters of computer keyboards commonly used in North America. ISO/ASTM 52915 specifies the additive manufacturing file format (AMF) that is used in 3D printing technology.

[10]For example, the International Organization for Standardization (ISO) stresses that its standards are voluntary. In a similar vein, European standards, even though sometimes requested by the European Commission, remain voluntary. In certain instances, standards are elaborated to support and interpret government regulation, but their use often remains voluntary.

nature unless government texts mandate its use.[11]

While our database does not allow us to identify regulatory standards, we can get an estimate for the relative magnitudes of regulatory and voluntary standards for the United States. When restricting our sample to SSOs that can be found in a database of US regulatory standards, the latter comprise less than 5% of the number of documents in our database.[12] Voluntary standards cover a wide variety of products, thus extending beyond health, safety or environmental aspects that typically make up regulatory trade barriers. By way of comparison, regulatory standards notified to the WTO[13] amount to 19,823 measures over the period 1995–2014 while our database contains roughly 1.1 million standard documents of which 548,123 are harmonized standards (the database is described in detail in Section 4).[14] This difference highlights the extent and effort of SSOs to establish common product features though voluntary standards.

The voluntary nature of the bulk of standardization activity has important implications for the underlying economic mechanisms. Governmental intervention in the form of *regulatory* standards is often associated with tackling market failures caused by the presence of negative externalities, where consumers do not take into account certain product features (e.g. goods produced using highly polluting technologies).[15] By contrast, *voluntary* standards define product attributes that users value; otherwise producers have few incentives to use the standard. Internet protocols, railway gauges or financial service standards are examples of how compatibility standards increase consumer utility by generating network externalities and scale effects. Standards can also reduce distortions arising from information frictions. For example, the labeling and certification of agricultural products allows consumers to distinguish high from low quality. Labels, certification and measurement standards lower search and transaction costs by reducing the effort spent on the verification of product attributes. Similar arguments apply to technical standards that producers of highly complex, technological products can simply refer to instead of using extensive product descriptions (e.g. for electronics or pharmaceuticals).[16]

[11] The possibility of a voluntary standard becoming legally binding could create uncertainty about future trade policy as in Handley and Limão (2017). The resulting reduction in trade flows suggests that any estimates of positive effects due to the release of voluntary standards are likely a lower bound and would increase if one were able to account for the introduced trade policy uncertainty.

[12] We obtain data from the National Institute of Standards and Technology's database on Standards Incorporated by Reference (SIBR) which tracks standards that are incorporated into US federal regulation and are therefore mandatory. When restricting our database to US SSOs that we can match to the SSOs in SIBR, our database comprises 226,482 documents while the equivalent number in SIBR is only 10,696 (4.7%). We are not able to match the databases on the document level and can only compare the aggregate number of documents per SSO.

[13] WTO member countries are required to notify the WTO of any release of a regulatory standard that concerns a tradable product or service and is not an international standard (see Article 2 of the WTO Agreement on Technical Barriers to Trade).

[14] The public versions of the WTO's Sanitary and Phytosanitary Information Management System (SPS IMS) and Technical Barriers to Trade Information Management System (TBT IMS) do not contain the name or identifier of the regulatory standard, preventing us from matching it to our database.

[15] Regulatory standards can be issued for other reasons than addressing a negative consumption externality, such as "regulatory protectionism" (Grossman et al., 2021) or allocation inefficiencies due to excessive entry (Macedonia and Weinberger, 2022).

[16] Consumer preferences for a certain attribute can result in voluntary standards becoming *de facto* binding. In this case, consumer demand guides firms in the production of goods. For example, consumers expect

The aforementioned benefits notwithstanding, the introduction of voluntary standards can lead to a smaller number of existing varieties due to sectoral reallocation as demand for standardized varieties rises to the detriment of non-standardized ones. This reduces the overall number of varieties and weighs negatively on consumer welfare. It is worth noting that standardization can also lead to market concentration or harm growth. Indeed, the microeconomic literature and policy discussions on standardization have pointed out the delicate balance SSOs have to strike when considering their impact on market power (Lerner and Tirole, 2015; Schmalensee, 2009; Llanes and Poblete, 2014) or the optimality of the chosen standard for innovation and long-term growth (David, 1985; Farrell and Saloner, 1985, 1986) if industries become "locked in" a certain standard.

We incorporate some of the elements described above into our theoretical framework. First, we consider product standards as product attributes that consumers value (though compliance with a standard involves sunk investment costs). Second, our model features endogenous standard adoption by firms who decide whether to produce according to a voluntary standard or not. Third, the CES structure of consumer demand allows for within- and cross-sectional reallocation, therefore allowing standardization to endogenously change the number of varieties.

3 Theoretical framework

General set-up. Our theoretical framework is a modified version of the Melitz (2003) - Chaney (2008) framework. Heterogeneous firms face a sector k-specific CES demand with elasticity of substitution σ_k, fixed costs of exporting from country i to country j, f_{ijk}, as well as variable iceberg trade costs τ_{ijk}. Quantities exported from country i to country j in sector k are denoted by c_{ijk}. Consumption in sector k in j is given by a CES basket:

$$C_{jk} = \left[\sum_{i=1}^{N} \int_{\omega \in \Omega_{ijk}} \left[z_{ijk}(\omega) c_{ijk}(\omega) \right]^{\frac{\sigma_k - 1}{\sigma_k}} d\omega \right]^{\frac{\sigma_k}{\sigma_k - 1}} \tag{1}$$

The term $z_{ijk}(\omega)$ captures the voluntary product standard that is applied by producers from country i selling to country j in sector k. The term z_{ijk} acts as a demand shifter that translates these product attributes into demand equivalents. On the one hand, we can think of z_{ijk} as capturing horizontal differentiation where $z_{ijk} > 1$ indicates that consumers value a product more if it corresponds to their ideal product attribute. Thus, two products might be characterized by the same level of quality (for example A4 and letter size for paper formats), but consumers in different countries might value them differently, according to their preferences. Alternatively, we can also incorporate vertical differentiation. In this case, standards enable consumers to better assess product attributes through certification or labelling and $z_{ijk} > 1$ captures the quality level.[17]

a printer to be compatible with A4 paper size (ISO 216:2007) or letter size (ANSI/ASME Y14.1) despite there being no official law on paper dimensions for printers.

[17] We intentionally abstract from modelling the role of regulatory standards in reducing negative externalities as it is the case in the models of Parenti and Vannoorenberghe (2022), Maggi and Ossa (2020)

For aggregate demand, we assume that demand for goods produced in different sectors k is determined by the following utility function:

$$U_j = \left(\sum_{k=0}^{K} C_{jk}^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}} \quad , \quad \gamma > 0 \tag{2}$$

where γ describes the elasticity of substitution across sectors. From the consumer maximization problem, we can derive demand for variety-specific exports from country i to country j in sector k, given by:

$$c_{ijk}(\omega) = A_{jk} z_{ijk}(\omega)^{\sigma_k - 1} p_{ijk}(\omega)^{-\sigma_k} \tag{3}$$

where $A_{jk} = P_{jk}^{\sigma_k} C_{jk}$ summarizes destination-specific sector demand and the corresponding price index, which is defined as follows:

$$P_{jk} = \left(\sum_{i=1}^{N} \int_{\omega \in \Omega_{ijk}} \left[\frac{p_{ijk}(\omega)}{z_{ijk}(\omega)} \right]^{1-\sigma_k} d\omega \right)^{\frac{1}{1-\sigma_k}} \tag{4}$$

Firms maximize profits by choosing prices given the product standard $z_{ijk}(\omega)$. Firm costs are affected by z_{ijk} in two ways. First, the implementation of a product standard $z_{ijk}(\omega)$ necessitates sunk investment costs $a(z_{ijk}(\omega))$. These capture the idea that a product standard requires firms to change existing production structures to produce in accordance with the specifications outlined in the standard document (see Shepherd, 2007). Second, marginal production costs $z_{ijk}^{t_k}(\omega)$ can also depend on the product attributes. In the case of vertical differentiation, the parameter $t_k \in (0, 1)$ captures the elasticity of marginal costs with respect to the standard and assures that marginal costs (and thus the price that firms charge) rise with higher quality. In the case of horizontal differentiation, $t_k = 0$ implies no additional marginal costs and the variable $z_{ijk}(\omega)$ simply acts as a demand shifter that signals consumer preferences for one product attribute rather than another.

Firms face variable iceberg costs of exporting τ_{ijk} as well as fixed costs of exporting f_{ijk}. They differ in their productivity φ to produce their respective variety and choose whether to produce the standardized or non-standardized variety.[18] If a firm chooses to produce in accordance with the standard, it receives additional demand $z_{ijk} > 1$ which is the same for all firms producing the standard. Firms that choose not to produce in accordance with the standard receive no additional demand, thus $z_{ijk} = 1$. Firms' profits

or Costinot (2008). In these models, governments choose the optimal regulatory standard to reduce a negative externality (e.g. pollution) associated with the consumption of the good by requiring firms to produce certain product characteristics (e.g. lower emissions). In our analysis, consumers value the benefits from standardized goods (e.g. that these goods are of higher quality or allow for network effects) because otherwise no firm would be willing to incur the associated sunk investment cost.

[18] Given that each firm is producing a distinct variety, we can index varieties (ω) by firm productivity (φ).

are:

$$\pi_{ik}(\varphi) = \sum_{j=1}^{N} p_{ijk}(\varphi)c_{ijk}(\varphi) - \frac{w_i \tau_{ijk} z_{ijk}^{t_k}(\varphi)}{\varphi} c_{ijk}(\varphi) - w_i f_{ijk} - w_i a(z_{ijk}(\varphi)) \tag{5}$$

Firms then choose their optimal price given the product standard, demand and their idiosyncratic productivity:

$$p_{ijk}(\varphi) = \frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk} z_{ijk}^{t_k}(\varphi)}{\varphi} \tag{6}$$

Substituting for product demand and the optimal price, we obtain firm export sales $x_{ijk}(\varphi)$ and profits $\pi_{ijk}(\varphi)$:

$$x_{ijk}(\varphi) = A_{jk} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk}}{\varphi} \frac{z_{ijk}^{t_k}(\varphi)}{z_{ijk}(\varphi)} \right)^{1-\sigma_k} ; \; \pi_{ijk}(\varphi) = \frac{x_{ijk}(\varphi)}{\sigma_k} - w_i(f_{ijk} + a(z_{ijk}(\varphi))) \tag{7}$$

Endogenous standard adoption. Our benchmark is a situation where the respective SSO in each country issues a national k-specific product standard. For ease of exposition, we consider a two-country world ($N = 2$). The two countries are denoted by subscripts i and j. Firms can choose whether to export a standardized product (we denote those firms with the superscript n) or a non-standardized product (no superscript). We focus on the case where consumers value only products that are in accordance with the standards released by their respective national SSOs, while they ignore product attributes that are prescribed by foreign standards, i.e. $z_{ijk} = z_{jk}$.[19] Standardizers have to pay the sunk investment costs $a(z_{jk})$, whereas non-standardizers do not pay any investment costs but forego demand effects:

$$\begin{array}{lll} \text{Standardizers:} & z_{ijk} = z_{jk} > 1; & a(z_{jk}) > 0 \\ \text{Non-standardizers:} & z_{ijk} = 1; & a(z_{jk}) = 0 \end{array} \tag{8}$$

The presence of sunk investment costs introduces a selection effect that results in only high-productivity firms willing to produce the standardized variety (the conditions of this partitioning are derived in Appendix A). As a consequence, there are two export cut-offs. The first cut-off ($\bar{\varphi}$) designates the firm that is indifferent between entering the export market or not. The second cut-off ($\bar{\varphi}^n$) designates the exporter that is indifferent between exporting the standardized variety or non-standardized variety.[20] The firm has to weigh the sunk investment costs to produce according to the standard z_{jk} against the additional

[19] We also consider a version where consumers value standards from the exporting country similar to Podhorsky (2013). This extension, available upon request, changes the trade-off between national and harmonized standards but the main empirical implications of our simplified model remain valid.

[20] If the additional demand from producing the standardized variety is large enough, i.e. the marginal exporter finds it worthwhile to produce in according with the standard, there exists only one exporter cut-off productivity. Given that our empirical estimates support the view of two productivity cut-offs, the discussion focuses on this case.

demand for standardized products ($s(z_{jk}) = z_{jk}^{(\sigma_k-1)(1-t_k)} - 1$) relative to non-standardized products. The two export cut-offs are given by:

$$\bar{\varphi}_{ijk} = \left(\frac{\sigma_k w_i f_{ijk}}{A_{jk}}\right)^{\frac{1}{\sigma_k-1}} \frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \tag{9}$$

$$\bar{\varphi}^n_{ijk} = \left(\frac{\sigma_k w_i a(z_{jk})}{s(z_{jk}) A_{jk}}\right)^{\frac{1}{\sigma_k-1}} \frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk}. \tag{10}$$

Next, we can write total bilateral export sales of country i to country j as the sum of the sales of firms that produce the standardized varieties (firms with productivity in the interval $\bar{\varphi}^n < \varphi < \infty$) and firms that produce the non-standardized variety (firms with productivity in the interval $\bar{\varphi} < \varphi < \bar{\varphi}^n$).[21] Assuming a Pareto distribution over the interval $[1, \infty]$ with product-specific shape parameter ξ_k, we write product-specific bilateral trade flows as:

$$X^n_{ijk} = \left(\frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \left(\sigma_k \frac{w_i f_{ijk}}{A_{jk}}\right)^{\frac{1}{\sigma_k-1}}\right)^{-\xi_k} \Gamma_k w_i f_{ijk} \left(1 + \Delta^n_{ijk} s(z_{jk})\right) \tag{11}$$

where $\Gamma_k = \frac{\xi_k \sigma_k}{\xi_k - (\sigma_k - 1)}$. The release of a voluntary national standard increases bilateral trade flows because of higher demand captured by $s(z_{jk})$; this is reflected in the share of exporters that decide to produce in accordance with the standard captured by the term

$$\Delta^n_{ijk} = \left(\frac{s(z_{jk}) f_{ijk}}{a(z_{jk})}\right)^{\frac{\xi_k}{\sigma_k-1}-1}. \tag{12}$$

Harmonized product standards. Instead of issuing national standards, the SSOs in countries i and j may decide to issue a common harmonized standard z_k that is equivalent in both countries. The advantage of issuing harmonized standards is that they allow for cost complementarities in sunk investment costs across markets, i.e. a firm has to pay the sunk investment cost $a(z_k)$ once and benefits from higher demand in both markets. Firms that choose to invest in the harmonized standard (superscript h) pay the sunk investment costs $a(z_k)$. Non-standardizers do not pay any investment costs but forego demand effects:

$$\begin{array}{lll} \text{Standardizers:} & z_{ijk} = z_k > 1; & a(z_k) > 0 \\ \text{Non-standardizers:} & z_{ijk} = 1; & a(z_k) = 0 \end{array} \tag{13}$$

As in the case with national standards, there are two export cut-offs. The first cut-off ($\bar{\varphi}$) designates the firm that is indifferent between entering the export market or not and is given by equation 9. The second cut-off ($\bar{\varphi}^h$) designates the exporter that is indifferent

[21] The detailed aggregation can be found in Appendix A.

between exporting the harmonized standardized variety or the non-standardized variety:

$$\bar{\varphi}_{ijk}^{h} = \left(\frac{\sigma_k w_i a(z_k)}{s(z_k)\left(A_{ik} + A_{jk}\tau_{ijk}^{1-\sigma_k}\right)} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k w_i}{\sigma_k - 1} \tag{14}$$

The cut-off productivity under harmonization highlights the cost complementary via the inclusion of the domestic market size A_{ik}. A larger home and destination market reduces the importance of sunk investment costs and encourages more firms to invest in the product standard. The mechanism is similar to Lileeva and Trefler (2010) and Bustos (2011) with the difference that, in our model, investment is incentivized through higher demand and cost complementarities rather than improved market access through lower tariffs.

Following the previous aggregation steps and using the assumption on the Pareto distribution, we can write bilateral trade flows under harmonized standards as follows:

$$X_{ijk}^{h} = \left(\frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \left(\sigma_k \frac{w_i f_{ijk}}{A_{jk}} \right)^{\frac{1}{\sigma_k - 1}} \right)^{-\xi_k} \Gamma_k w_i f_{ijk} \left(1 + \Delta_{ijk}^{h} s(z_k)\right) \tag{15}$$

where Δ_{ijk}^{h} captures the share of firms that invest in the harmonized standard

$$\Delta_{ijk}^{h} = \left(\frac{s(z_k) f_{ijk}\left(A_{ik} + A_{jk}\tau_{ijk}^{1-\sigma_k}\right)}{a(z_k) A_{jk}\tau_{ijk}^{1-\sigma_k}} \right)^{\frac{\xi_k}{\sigma_k - 1} - 1} \tag{16}$$

and the term $s(z_k)$ describes the associated demand effect for firms that choose to invest in the standard. Equation 15 forms the basis for our empirical analysis.

Comparing equation 15 to equation 11, the difference between national standards and harmonized standards consists of two effects. The first effect is the cost complementarity effect (driven by $A_{ik} + A_{jk}\tau_{ijk}^{1-\sigma_k}$), which reduces market-specific investment costs. This induces more firms to produce in accordance with the harmonized standard ($\Delta_{ijk}^{h} > \Delta_{ijk}^{n}$ for similar levels of the product attribute $z_k \approx z_{jk}$) and increases the effect on bilateral trade. The second effect is a demand effect and captures the extent to which consumers value harmonized standards z_k differently from national standards z_{jk}. Potential drivers are differences in national preferences over product attributes (e.g. US "chlorinated chicken" exports to Europe) or positive network effects from reaching more consumers (e.g. phone devises that work both in the US and Europe).

Regulatory standards. How does our framework compare to the case of harmonized regulatory standards generally considered in the trade literature? If a harmonized standard becomes legally binding and compliance is mandatory, firms have to produce the product attribute (z_k) prescribed by the standard.[22] The productivity cut-off of the marginal firm

[22]This assumption is identical to models of regulatory standards such as Mei (2018) or Macedonia and Weinberger (2022).

being indifferent between entering the foreign market or not is now given by:

$$\left(\bar{\varphi}^{r}_{ijk}\right) = \left(\frac{\sigma_k w_i (f_{iik} + f_{ijk} + a(z_k))}{\left(A_{ik} + A_{jk}\tau_{ijk}^{1-\sigma_k}\right) z_{iik}^{(1-t_k)(\sigma_k-1)}} \right)^{\frac{1}{\sigma_k-1}} \frac{\sigma_k w_i}{\sigma_k - 1} \tag{17}$$

Equation 17 shows that the introduction of harmonized regulatory standards leads to changes in the number of exporters and depends on the relative importance of sunk investment costs, cost complementarities and the demand effect.

The higher demand for standardized varieties implies that all exporting firms should increase their sales. However, the presence of sunk investment costs implies a scale effect and leads to larger increases in the average production costs for smaller firms. As a result, the marginal firm that is indifferent between entering or not has to increase its export sales by more in order to break even. Overall, we expect that harmonized regulatory standards change the number of exporters and increase the export sales for all exporters along the firm-size distribution with higher magnitude for smaller firms. This size-effect differs from harmonized voluntary standards, where only a subset of exporters (i.e. the large ones) will choose to adopt the standard and experience changes in export sales. We will investigate the different implications on the extensive margin and the firm-size distribution in our empirical analysis on the importance of selection effects in Section 7.

Discussion on welfare effects. We briefly discuss the welfare implications of introducing voluntary harmonized standards within our model. These concern two dimensions. On the one hand, the standard leads to reallocation *within a sector* k. On the other hand, demand is reallocated *across sectors*. Equation 16 shows that the introduction of voluntary product standards will induce some firms to adopt the standard and increase their export sales. Within a sector k, the introduction of a standard shifts demand towards standardized varieties and increases bilateral exports. However, the standard reduces demand for non-standardized varieties and leads to fewer varieties within the sector. Given that the consumer has a preference for variety, this has a negative effect on consumer welfare. At the same time, the consumer benefits from the ability to consume higher-valued standardized varieties. One can show that the positive effect of higher-valued varieties outweighs the negative effect of fewer varieties and leads to more consumer expenditure in that sector.

A consequence of higher expenditures for the sector where the standard was introduced is lower demand in sectors without standards. This *cross-sector* reallocation could potentially lead to an overall reduction in consumer welfare, if the sector that introduces a standard has a low elasticity of substitution.[23] Low elasticities of substitution imply higher markups and a significant expenditure shift towards these sectors can lead to a higher overall price level in the economy. Appendix B discusses these cases within a symmetric two-country two-sector version of our model.

[23] In our welfare comparison in Appendix B we follow Melitz and Redding (2015) and compare consumer utility in the absence of standards to consumer utility after the introduction of a harmonized standard for identical parameter values. These parameters are demand elasticities, fixed costs, entry costs, the shape parameters of the Pareto distribution, trade costs and labour endowment.

To summarize, our theoretical framework provides an estimation equation and sheds light on the underlying mechanism through which voluntary standard harmonization affects bilateral trade flows. The model suggests that the estimated treatment effect of standard harmonization depends on the number of firms that adopt the standard and the associated change in their export sales. This treatment effect is heterogeneous and varies with bilateral trade costs as well as with product and country characteristics. The estimations in Sections 5 and 7 will provide empirical evidence on these predictions. Next, we describe our dataset and discuss how we assign product standards to the product categories in the trade data.

4 Data

We track the standard releases of each SSO in the Searle Center Database on Technology Standards, Industry Consortia and Innovation (Baron and Spulber, 2018), and use information on standard equivalences in order to identify cross-country standard harmonization. The dataset contains the date of release, the International Classification for Standards (ICS) category and the nationality of the SSO. An SSO can release a standard developed by its own technical committee, but can also release a standard developed by another SSO.[24] In order to identify relevant harmonization events, we restrict the sample to those standards that constitute the first publication ("original") across all SSOs/nationalities as well as the accreditation of these original standards by SSOs of different nationalities.

In our dataset, there are two means via which product standards are harmonized across countries. Either an SSO decides to accredit the standard of an SSO of another nationality or two SSOs of different nationalities accredit a standard originating in an international SSO. Of all accreditations that we observe in our database, 5% concern the accreditation of a standard that was originally released by a national SSO while the bulk of all accreditations, i.e. 95%, concern international standards. A large amount of this international dimension of standard harmonization is due to the European integration process and the accompanying dominance of European SSOs among international SSOs. National SSOs play only a minor role (see Appendix D for more details on the number of original standards and accreditations in our dataset as well as the prevalence of international SSOs). We define harmonization as follows: an SSO of the importing country releases a standard document that was also released by an SSO of the exporting country (either in the same year or before).[25]

Our definition of standard harmonization comprises both standard releases that concern aspects which were previously not subject to a product standard (either because there was

[24] This is for example the case when a standard released by an international SSO such as the International Organization for Standardization (ISO) is published by a national SSO such as the British Standards Institution (BSI).

[25] With respect to mutual recognition, we are not able to identify these events in the data. This would require knowing that the accreditation of a trading partner's standard was specifically part of a mutual recognition procedure. An alternative form of mutual recognition, as in the case of the EU, does not necessarily involve the formal accreditation of a trading partner's product standards and consequently does not show up in our dataset.

no standard or because the product/technology did not yet exist) or standard harmonization in the strict sense where conflicting standards are replaced by one common, harmonized version. We designate the term "standard harmonization" to apply both to the release of a new, harmonized standard as well as to the replacement of conflicting standards.

In terms of sectoral heterogeneity, standards are categorized according to the International Classification for Standards (ICS).[26] Table 1 shows that cross-country standard harmonization is very prevalent in materials technologies, electronics and ICT as well as engineering technologies. Note that a standard can be classified into more than one ICS category.

Table 1: Releases of harmonized standards, by major ICS categories

Field	Number	in %
Agriculture and food technologies	26,381	3.2
Construction	82,194	10.0
Electronics, information technology and telecommunications	131,655	16.1
Engineering technologies	140,721	17.2
Generalities, infrastructures and sciences	90,811	11.1
Health, safety and environment	91,942	11.2
Materials technologies	141,711	17.3
Special technologies	29,051	3.5
Transport and distribution of goods	84,791	10.3
Total	819,257	100

Notes: The table displays the number of standard releases, broken down by major ICS categories, after having excluded within-country accreditations. The categories are Agriculture and food technologies [ICS 65–67]; Construction [ICS 91–93]; Electronics, information technology and telecommunications [ICS 31–37]; Engineering technologies [ICS 17–29 and 39]; Generalities, infrastructures and sciences [ICS 01–07]; Health, safety and environment [ICS 11–13]; Materials technologies [59–61 and 71–87]; Special technologies [95–97]; and Transport and distribution of goods [ICS 43–55]. Appendix C lists the ICS classes in detail. A number of standards belong to more than one ICS class (disaggregated at the 5-digit level). The data are summed over the years 1995–2014 and all SSOs.

The next step is to relate the standard documents to products traded in international markets. The data source for bilateral product trade flows is the BACI database developed by the CEPII; see Gaulier and Zignago (2010). BACI reconciles export and import declarations of values and volumes in the United Nations COMTRADE database by giving precedence to the reporting of importing countries and provides a time-consistent product classification. The data are classified according to the 1992 Harmonized System (HS) established by the World Customs Organization (WCO) with standardized 6-digit codes common to all countries. By contrast, product standards are classified according to the International Classification for Standards (ICS) system. The non-existence of a concordance between these two classifications is one of the main reasons why previous papers in the literature cover only certain sectors: see Moenius (2006), Reyes (2011) or Fontagné et al. (2015).

[26] See the table in Appendix C for the first level of disaggregation of the ICS.

We tackle the concordance issue in two ways. First, we use a newly developed concordance table from the WTO with the drawback that some links between key standard categories and products might be missing (see Appendix E for more details). As a second step, we develop a new all-industry concordance table using keyword-matching techniques and describe our methodological approach in a companion paper (Han et al., 2019). The main advantage of this table is that it covers all ICS and HS categories. The WTO concordance does not classify the "Generalities, infrastructures and sciences" sector. Both concordance tables create links between the 5-digit ICS standard categories and 4-digit HS product categories. We link the standard harmonization events at the country-pair level to the corresponding product and aggregate all harmonization events within a 4-digit HS product (1,250 different categories). The resulting dataset varies by exporter, importer, product and year and is the basis for our empirical analysis. The final sample size consists of all bilateral sector linkages between the 26 countries[27] for the period 1995-2014 and results in 6.7 million observations with a positive trade flow. Of these observations, 42% are subject to at least one standard harmonization.

The results in the next section are based on the WTO concordance table, while the results using the concordance table based on keyword-matching techniques can be found in Appendix F. At this point, we want to stress that even though our standard database is a comprehensive database covering the most important industrialized and emerging countries, we cannot exclude under-reporting for specific countries or standard setting organizations. Our regression specification includes time-varying product-specific fixed effects for exporting and importing countries to minimize the risks from under-reporting. As we measure the explicit release of harmonized standard documents, our results should thus be interpreted as pertaining explicitly to *formal* harmonization.

5 Empirical framework and results

Our empirical framework consists of two parts. In the first part, we estimate the effect of standard harmonization on bilateral trade flows using product-level data. The main advantages of this approach are: (1) the inclusion of a rich set of fixed effects that allow us to simultaneously control for demand and supply conditions and (2) the quantification of the importance of standard harmonization for global trade. The main disadvantage is that the product-level data do not allow us to quantify the model implied selection effect at the firm-level. For this reason, we corroborate our empirical analysis with firm-level evidence from France. The details of this second approach will be discussed in Section 7.

5.1 Estimation equation

Our baseline estimation equation consists of a difference-in-difference approach and compares trade flows whose products were subject to a harmonization event with those that

[27] These countries are Australia, Austria, Brazil, Canada, China, the Czech Republic, Denmark, Finland, France, Germany, Italy, Jordan, Japan, Korea, the Netherlands, Norway, Poland, Russia, the Slovak Republic, South Africa, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

were not. Taking logs of our gravity equation 15, our estimation equation takes the following form:

$$\log X_{ijkt} = \beta h_{ijkt} + f_{ijk} + f_{ikt} + f_{ijt} + f_{jkt} + e_{ijkt} \tag{18}$$

where the log of bilateral exports of a product k depends on the number of harmonization events (h_{ijkt}) within that triplet. h_{ijkt} equals zero and increments by one whenever there is at least one standard that the importing country j harmonizes with the exporting country i in product k at time t. This definition of our harmonization variable implies that our regression focuses on the effect of country i's exports to country j when an SSO in country j accredits a standard already released (or being released the same year) in i. The decision of country j's SSO to accredit the harmonized standard is likely more exogenous to the exports of country i as in the alternative definition of focusing on the adopting country j's exports to country i. In the latter case, domestic firms in country j may lobby the decision of their SSO to adopt country i's standard if they expect to benefit from it, a point we address in more detail in Sections 6.3 and 6.4.[28]

Since our panel dataset allows us to compare harmonization events for different products in different countries, we include destination-specific (f_{jkt}), origin-specific (f_{ikt}), time-varying bilateral (f_{ijt}) and time-invariant bilateral product characteristics (f_{ijk}). These fixed effects capture differences in product-specific destination market size that varies over time (A_{jkt}), the total number of exporters from country i in product k in a given year t (M_{ikt}) and time-invariant bilateral trade costs at the product-level (f_{ijk} and τ_{ijk}). We later relax this assumption and include observable changes in trade costs as a control variable.

The coefficient of interest $\hat{\beta}$ measures the average treatment effect of standard harmonization on product-level exports. This treatment effect consists of the increase in firm export sales due to higher demand $\bar{s}(z_k)$, the average treatment of the treated, times the share of firms that select into treatment and produce in accordance with the standard. $\hat{\beta}$ also depends on parameters of the model, such as the sectoral demand elasticity, bilateral trade costs as well as destination market size.

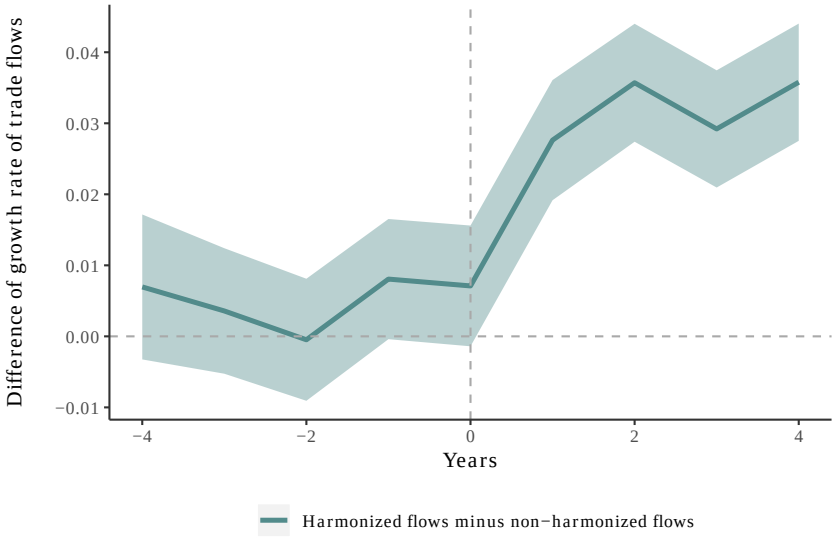
5.2 Baseline results

As a first glance at the data, we calculate the average growth rate of trade flows before and after a harmonization event and compare it with the growth rate of trade flows that were never subject to standard harmonization. The difference between the two is plotted in Figure 1. One notices a significantly higher growth rate for bilateral exports after the importer accredited the same standard as the exporter. Before the harmonization event,

[28] For most of the standard harmonization events this difference does not matter because 81% are symmetric, i.e. the SSO of the importing country j is releasing the same standard as the SSO in exporting country i in the same year. In this case the harmonization dummy captures the change in bilateral trade in both directions. As a robustness check, we re-estimate equation 18 with the alternative definition of exports from j to i as the dependent variable and obtain similar results as in Table 2. Detailed results are available upon request.

we do not observe any significant differences in the growth rates between the treatment and the control group.

Figure 1: Growth of trade flows around harmonization



Notes: This figure plots the difference in the mean growth rate between harmonized trade flows (treatment group) and non-harmonized trade flows (control group) before and after a harmonization event. The point 0 denotes the timing of the event. Growth rates below the 2.5th and above the 97.5th percentiles are excluded from the calculations.

To provide more formal evidence on the relationship plotted in Figure 1, we start by estimating regression equation 18 and add different sets of fixed effects and bilateral tariffs as a control variable. For the latter, we use the simple average applied tariff rate from the World Integrated Trade Solution (WITS) TRAINS data set from the World Bank.

The results are displayed in Table 2. Column (3) and column (4) are our preferred estimates as they include the full battery of fixed effects. Column (3) in Table 2 confirms the suggested positive effect of harmonized standard releases on trade flows in Figure 1. The estimated coefficient is statistically significant at the 1% level and implies that, on average, a harmonization event increases bilateral trade flows by 0.59%. Column (4) adds observed bilateral product-level tariff rates in the importing country j as an additional control variable. The point estimate in this specification is slightly lower than in column (3) but still significant at the 10% level. Column (1) and column (2) in Table 2 show the importance of controlling for unobserved characteristics. Without controlling for product-specific effects, the estimated effect would be more than 20 times larger and 3 times larger if we did not control for time-varying bilateral effects such as signing a preferential trade agreement or any other aggregate changes in the bilateral trade relationship.

Table 2: Regression results / Baseline specification

Dependent variable:	log(exports)			
	(1)	(2)	(3)	(4)
Harm.	0.14804***	0.01973***	0.00585***	0.00360*
	[0.00359]	[0.00122]	[0.00175]	[0.00188]
Ln(1+tariff)				-2.97944***
				[0.45869]
Observations	5931947	5860751	5860748	4704889
R^2	0.21	0.88	0.88	0.89
Adjusted R^2	0.21	0.85	0.85	0.86
Exporter-time FE	yes	no	no	no
Importer-time FE	yes	no	no	no
Exporter-importer FE	yes	no	no	no
Exporter-product-time FE	no	yes	yes	yes
Importer-product-time FE	no	yes	yes	yes
Exporter-importer-product FE	no	yes	yes	yes
Exporter-importer-time FE	no	no	yes	yes

Notes: Regression of the log of bilateral product-level exports on harmonization indicator with different sets of fixed effects (FE). The number of observations changes because of multicollinearity when including more fixed effects. Standard errors are clustered at the exporter-product-level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

5.3 Ad-valorem equivalents and contribution to growth in global trade

How does the increase in trade flows from standard harmonization compare to observable trade costs? To answer this question, we calculate the ad-valorem equivalent (AVE) of tariffs following Kee et al. (2009). They define the AVE in non-tariff measures (in our case, harmonized standard releases) as the equivalent of the ad-valorem tariff rate that induces the same proportionate change in the trade value adjusted by the import demand elasticity (σ):

$$AVE = \left(\frac{\exp(\beta) - 1}{\sigma} \right) 100. \tag{19}$$

To obtain an estimate of the aggregate AVE, we take the estimate of the harmonization dummy in column (3) of Table 2 for β and the estimated coefficient of the average applied tariff rate minus one for the import demand elasticity.[29] These values imply that the aggregate AVE equals -0.15, which we interpret as an implicit export subsidy in the range of 0.15 percentage points.

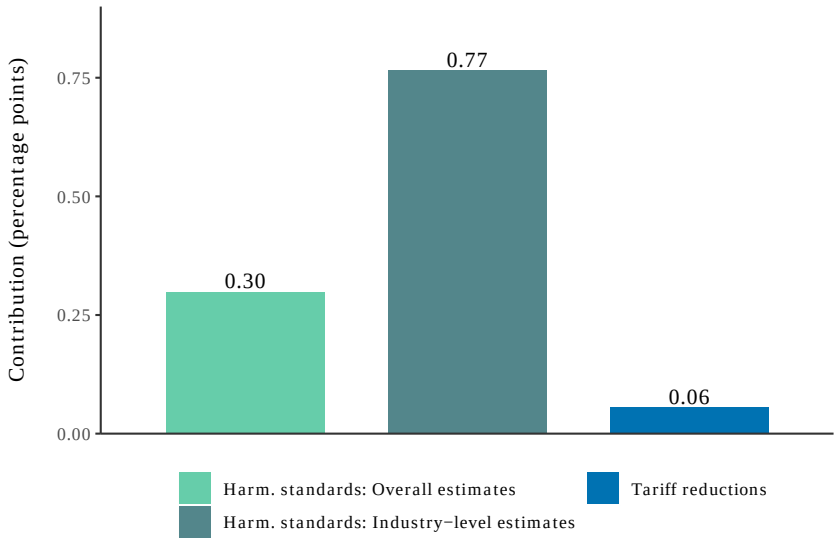
The AVE translates the econometric estimate of each individual harmonization event into comparable economic magnitudes. The implied effect that is equivalent to -0.15 percentage points in the tariff rate is small, but this is not surprising given that these events are defined at the 4-digit HS level (a specific standard could only be relevant at a lower level of disaggregation) and cover a large number of standards that differ in their coverage and impact (a specific standard might present considerable advantages or only present marginal benefits for its users). In order to assess the overall impact of harmonized

[29] The implied demand elasticity of -3.9 is close to the value 4 commonly used in the literature, see Head and Mayer (2014).

standard releases, we need to consider the number of times product groups are subject to a harmonization event.

We use the point estimates of the harmonization indicator to calculate the implied increase in total trade flows among the countries and industries in our sample and compare it with the contribution of tariff reductions. We multiply the harmonization dummy by either (1) the point estimate of the full sample in column (3) of Table 2 or (2) the sector-specific point estimates of regression 18 and calculate the trade-weighted average increase in trade flows due to standard harmonization.[30] We then compare these estimates with the trade-weighted increase in trade flows due to tariff reductions. Figure 2 shows that over the years 1995–2014 standard harmonization increases global trade flows by 0.30% per year using our aggregate estimate and by 0.77% using our industry-specific estimates. This corresponds to respectively 5% and 13% of the average observed annual increase in global trade between 1995 and 2014. During the same period, the increase in global trade due to tariff reductions is 0.06% and considerably smaller than the increase due to the introduction of harmonized standards. The reason for this higher contribution despite the low point estimates is that almost 42% of our products are subject to standard harmonization within a given year, while only a few products experience tariff reductions and these reductions were small in magnitude. During our sample period, the average yearly reduction in the applied tariff rate between the countries in our sample was 0.16 percentage points.

Figure 2: Increase in trade flows due to harmonized standards and tariffs



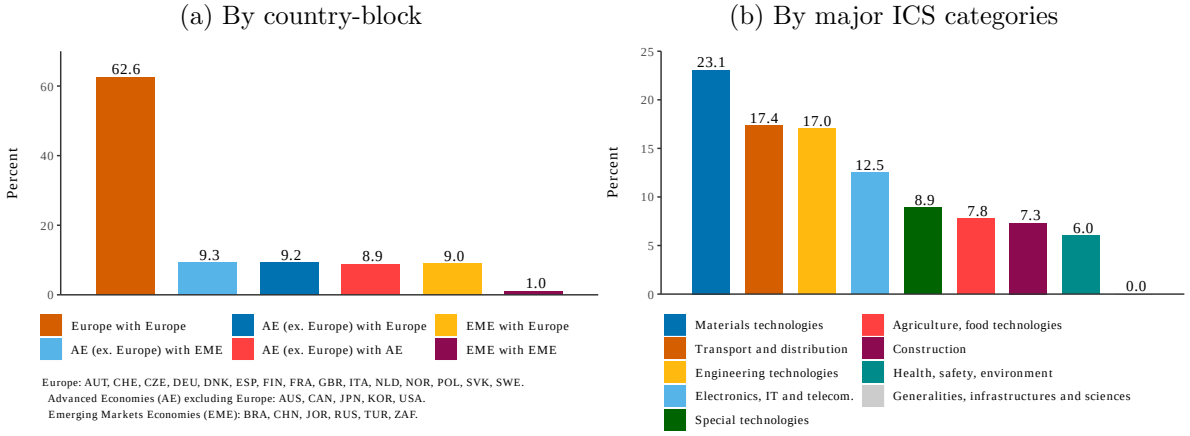
Notes: This figure depicts the implied increase in global trade, averaged over 1995–2014, due to harmonization events and tariff reductions. The overall estimate of the implied contribution is based on the baseline regression 18 whereas the sector-level estimate is based on individual regressions that are run on the level of each 4-digit HS-sector.

To shed light on the geographical drivers of the implied increase in global trade, we decompose the overall contribution to trade due to the release of harmonized standards by

[30] Using the sector-specific regression specification, we obtain a marginal effect of standard harmonization on bilateral exports for each 4-digit HS category.

country group. In particular, we consider three different groups: (1) European countries, (2) Advanced Economies excluding Europe and (3) Emerging Market Economies.[31] Panel (a) of Figure 3 plots the estimated increase due to standard harmonization for each country group and the possible interactions with other country groups. The overall increase in global trade is largely driven by harmonization events between European countries. Their share accounts for more than 62% of the total increase. The second largest contribution comes from harmonization events between Emerging Market Economies and other Advanced Economies with a share of 9.3%. Harmonization events among Emerging Market Economies are rare relative to those in other country groups and make up only 1.0% of the total implied increase in global trade that can be related to the introduction of harmonized standards.

Figure 3: Disaggregation of the implied contribution to growth in trade



Notes: This figure depicts the disaggregation of the implied increase in global trade, averaged over 1994–2015, due to harmonization events by country group and by major ICS categories. In panel (b), these categories are Agriculture and food technology [ICS 65–67]; Construction [ICS 91–93]; Electronics and ICT [ICS 31–37]; Engineering technologies [ICS 17–29 and 39]; Generalities, infrastructures and sciences [ICS 01–07]; Health, safety and environment [ICS 11–13]; Materials technologies [59–61 and 71–87]; Special technologies [95–97]; and Transport and distribution of goods [ICS 43–55]. Appendix C lists the ICS classes in detail.

In a similar vein, we ask which standards drive the results in terms of the products and topics they cover. We group standards according to the ICS classification in Table 1 and calculate their contribution to the increase in global trade. Panel (b) of Figure 3 shows that standards classified as belonging to "Materials technologies", "Transportation" and "Engineering technologies" contribute the most. Their combined share adds more than 57% to the implied increase in global trade. Standards categorized in the "Health, safety and environment" classes account for only 6% of the implied increase in global trade.

Taken together, these results reveal that, during our sample period, harmonized standard releases among the countries in our sample contributed significantly more to global trade growth than tariff reductions. This increase is mainly driven by the use of

[31] European countries are Austria, Switzerland, the Czech Republic, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, the Netherlands, Norway, Poland, the Slovak Republic and Sweden. Advanced Economies excluding Europe include Australia, Canada, Japan, South Korea and the United States. Emerging Market Economies are defined as Brazil, China, Jordan, Russia, Turkey and South Africa.

harmonized standards among European economies, which reflects the European integration process during this period and the prominent role of European SSOs in the standard-setting process. Section 6.3 sheds more light on this question. In terms of types of standards, the results are largely driven by technology standards. Health, safety and environmental standards, which are the main focus in the literature on regulatory trade barriers, play only a minor role.

6 Endogeneity and robustness

This section addresses potential identification concerns and endogeneity issues. The first identification concern is that harmonization primarily happens in product categories where trade flows are generally large; higher trade flows after the release of harmonized standards are thus simply a result of the preference of SSOs to standardize more important product categories. This would violate the assumption of parallel pre-trends in our difference-in-difference setting. Second, special interest groups or firms may lobby for the accreditation of a standard in the anticipation of higher sales. In order to address these concerns, we want to point out that all our regressions include a rich set of fixed effects that controls for any non-discriminatory or regulatory standards common to all exporters or importers. Below, we resort to several robustness tests, namely (1) estimating our regression model in differences and including product-specific bilateral time trends, thus ruling out size and growth effects of large trade flows, (2) testing for the existence of pre-trends, (3) assuring that the standards in question have a supranational and thus largely exogenous character (by testing so-called European Standards) and (4) using the harmonization events of neighboring countries as an instrument for a country's own events. Finally, we briefly mention additional robustness tests that we report in Appendix F.

6.1 Difference equation

One key identification concern is that our main results in Table 2 are driven by the fact that standard harmonization events primarily happen in sectors where exporters are already present and where trade volumes are high. To address part of these concerns, we specify our baseline regression in terms of first differences:

$$\Delta X_{ijkt} = \beta \Delta h_{ijkt} + f_{ikt} + f_{jkt} + f_{ijt} + f_{ijk} + \varepsilon_{ijkt} \tag{20}$$

and include controls for product-specific bilateral time trends (f_{ijk}). These fixed effects account for the identification concern that countries may harmonize standards for trade flows that grow, on average, at a higher rate. The variable of interest, Δh_{ijkt}, is the first difference of the cumulative measure of standard harmonization h_{ijkt}. Δh_{ijkt} is a binary indicator that equals one in the year the standard harmonization took place and zero otherwise. In addition, we follow Baier et al. (2014) and allow for multi-year differences. The regression equation appears as follows:

$$\Delta_m X_{ijkt} = \beta \Delta_m h_{ijkt} + f_{ikt} + f_{jkt} + f_{ijt} + f_{ijk} + \varepsilon_{ijkt}, \tag{21}$$

where Δ_m indicates differencing the dataset by m years. The reasons for multi-year differencing are twofold. When differencing the data by several years, the reference year in the control and treatment group is shifted back in the past. As a consequence, the regression set-up picks up some of the longer-run effects and also safeguards against anticipation effects (if any effect of standard harmonization is already present in the year before the actual release, differencing by several years makes the result more robust to such an anticipation effect).

Table 3: Regression results / Multi-year differences

(a) Without product-specific bilateral trends f_{ijk}

Dependent variable:	log(exports)				
	(1) Δ_{t-1}	(2) Δ_{t-2}	(3) Δ_{t-3}	(4) Δ_{t-4}	(5) Δ_{t-5}
Harm.	0.00219	0.00456**	0.00579***	0.00453***	0.00445***
	[0.00223]	[0.00177]	[0.00154]	[0.00140]	[0.00130]
Observations	5027623	4686515	4380328	4087464	3802742
R^2	0.22	0.25	0.27	0.30	0.32
Adjusted R^2	0.08	0.11	0.14	0.16	0.19
Exporter-product-time FE	yes	yes	yes	yes	yes
Importer-product-time FE	yes	yes	yes	yes	yes
Exporter-importer-product FE	no	no	no	no	no
Exporter-importer-time FE	yes	yes	yes	yes	yes

(b) With product-specific bilateral trends f_{ijk}

Dependent variable:	log(exports)				
	(1) Δ_{t-1}	(2) Δ_{t-2}	(3) Δ_{t-3}	(4) Δ_{t-4}	(5) Δ_{t-5}
Harm.	0.00241	0.00486**	0.00491***	0.00304*	0.00306*
	[0.00245]	[0.00206]	[0.00189]	[0.00182]	[0.00180]
Observations	4998200	4658270	4351612	4058592	3772639
R^2	0.25	0.30	0.33	0.38	0.42
Adjusted R^2	0.04	0.09	0.13	0.18	0.24
Exporter-product-time FE	yes	yes	yes	yes	yes
Importer-product-time FE	yes	yes	yes	yes	yes
Exporter-importer-product FE	yes	yes	yes	yes	yes
Exporter-importer-time FE	yes	yes	yes	yes	yes

Notes: Regression of the change in the log of bilateral product-level exports on the change of the harmonization indicator. Regression model corresponds to the differenced version of the baseline model (regression specification 21 with the corresponding set of fixed effects (FE)). Δ_{t-m} in columns (1)–(5) indicates differencing by m years. Robust standard errors are reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

The results are presented in Table 3 for one-, two-, three-, four- and five-year differences. Panel (a) shows the results without product-specific bilateral time trends while the results in panel (b) include these time-trends. Both panels show that after one year, the estimate of the growth rate of total trade flows is not statistically significant from zero. After two years, the effect increases to 0.46% and remains significant at around 0.3% to 0.58% after three, four and five years. These results are consistent with our baseline set-up (Table 2). While the baseline measures long-run average effects, the difference specification sheds light on the timing. Table 3 implies that the adaptation of new harmonized standards takes about two years until export sales start to increase.

6.2 Pre-trends

Another identification concern is that our difference-in-difference estimator picks up different pre-trends between harmonized and non-harmonized products. Different pre-trends arise if harmonization primarily happens in product categories where trade flows are large or when firms anticipate future standardization efforts and react prior to the actual harmonization event. Given that we have multiple harmonization events (i.e. repeated treatment at different points in time) within an exporter-importer-product triplet, we focus only on observations that did not have any standard harmonization four years prior to the first harmonization event.[32] The regression specification with pre-trends appears as follows:

$$\log(X_{ijkt}) = \beta_h h_{ijkt} + \sum_{n=1}^{4} \beta_n d^{1st}_{ijkt-n} + f_{ikt} + f_{jkt} + f_{ijt} + f_{ijk} + \varepsilon_{ijkt}, \tag{22}$$

where the variable d^{1st}_{ijkt-n} represents a dummy that is equal to one n years prior to the first harmonization event.

Table 4: Regression results / Controlling for pre-trends

Dependent variable:	log(exports) (1)
Harm.	0.00598***
	[0.00185]
Harm. (t-1)	0.00138
	[0.00273]
Harm. (t-2)	0.00006
	[0.00343]
Harm. (t-3)	0.00262
	[0.00402]
Harm. (t-4)	0.00090
	[0.00446]
Observations	5860748
R^2	0.88
Adjusted R^2	0.85
Exporter-product-time FE	yes
Importer-product-time FE	yes
Exporter-importer-product FE	yes
Exporter-importer-time FE	yes

Notes: Regression of the log of bilateral product-level exports on the harmonization indicator and dummy variables for the first harmonization event shifted in time. Fixed effects (FE) are included as described in the regression specification 22. Standard errors are clustered at the exporter-product-level and are reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

Results are displayed in Table 4. The magnitude of the coefficient for harmonization events implies an increase of 0.60% and is comparable to the baseline specification. The pre-trend dummies are not significant for any of the four years prior to the harmonization event.

[32] Since our sample starts in 1995, we do not consider any observations that experience a harmonization event prior to the year 2000.

6.3 Endogeneity and European Standards (EN)

One of the major endogeneity concerns is that large firms lobby SSOs to accredit product standards that are favorable to them. In general, SSOs elaborate standards in working groups and technical committees that are composed of industry experts, which participate on behalf of private firms as well as governmental and non-governmental organizations. While this mechanism allows private firms to influence the development and potential accreditation of a standard, their influence is limited by the voting power of other technical experts. Spulber (2019) shows that voting power and market power may have counterbalancing effects in reaching consensus that is needed in order to issue a standard. An additional limiting factor is that the firm needs to persuade all participating SSOs, foreign and national, in agreeing on the same standard.

While the voting mechanism reduces the endogeneity problem, we address remaining concerns by taking advantage of so-called European standards that have a supranational character. Once a standard is qualified as a European Standard (identified through the reference code containing the letters "EN"), it "carries with it the obligation to be implemented at national level by being given the status of a national standard and by withdrawal of any conflicting national standard" (CEN-CENELEC Internal Regulations[33]). Note that the obligation to incorporate the standard into national standard catalogues does not imply that these standards are legally binding, they remain voluntary unless referenced by government regulation. The European Commission actively supports the development of European Standards.

The supranational character of these European standards mitigates endogeneity concerns for two reasons. First, the influence of national firms is limited and non-European countries also accredit European Standards (EN), which makes it harder for European firms to lobby for the accreditation of a standard. Second, the timing of the accreditation of European Standards by national SSOs varies across countries. The majority of these accreditations take place with a lag of one or more years after the original release. The introduced uncertainty about the timing is important as the definition of the harmonization dummy relies on the year the national SSO accredits the standard and not on the time the EN standard was issued.

We run the same regression model as before, but limit the construction of the harmonization indicator to European standards. The results are displayed in Table 5. The results are quantitatively and qualitatively very similar to the baseline specification: using European Standards implies an increase in trade flows of 0.73% following a harmonization event.

[33]See https://www.cenelec.eu/standardsdevelopment/ourproducts/europeanstandards.html.

Table 5: Regression results / European Standards

Dependent variable:	log(exports) (1)
Harm.	0.00728*** [0.00195]
Observations	6128959
R^2	0.88
Adjusted R^2	0.85
Exporter-product-time FE	yes
Importer-product-time FE	yes
Exporter-importer-product FE	yes
Exporter-importer-time FE	yes

Notes: Regression of the log of bilateral product-level exports on harmonization indicator that only takes into consideration EN standards. Fixed effects (FE) are included as described in the regression specification 18. Standard errors are clustered at the exporter-product-level and are reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

6.4 IV regressions

We resort to instrumental variable techniques to further analyze to what extent our results are robust to the possibility that the accreditation of standards is subject to firm lobbying. A commonly used instrument for specific public policies are policies conducted by neighboring countries (see, for example, Buera et al., 2011 and Giuliano et al., 2013 in the specific context of trade policies). The underlying idea is that trade policies of neighboring countries, due to similarities in terms of economic structure or geographic characteristics, are a good predictor of a country's own policies, but are not the target of lobbying efforts by domestic firms. Using CEPII's GeoDist database (Mayer and Zignago, 2011), we identify an exporting country's neighbors among the countries in our database and calculate the mean number of harmonization events with respect to each importing country. If this average is larger than or equal to 0.5, we code it as a harmonization event ($h^{IV}_{ijkt} = 1$).

We consider a country to be a neighbor if it shares a common language or a land border with another country.[34] To address the concern that the results are driven by member countries of the European Union and their common trade policies, we conduct the analysis for the full sample and a reduced sample without EU member states.

The results using the full sample are displayed in columns (1) and (2) of Table 6, while the results for the sample consisting of non-EU members are shown in columns (3) and (4). Column (1) and column (3) display the results of the first stage: the mean number of harmonized standard releases of neighboring countries constitute a relevant predictor of a country's own harmonization events and the F-statistic dismisses the possibility that the IV estimates are biased due to weak instruments. The second-stage results, displayed in

[34] A certain number of countries do not share a language or border with any of the other countries in our database: Brazil, Japan, Jordan, South Korea and Turkey. For Japan and South Korea, we consider the countries with which they share a maritime border as neighbors. For Brazil, Jordan and Turkey, we define the three closest countries in our database as neighbors.

columns (2) and (4), show that overall trade increases significantly in both samples, which is in line with our baseline estimates.

In terms of economic magnitudes, the IV estimates are larger than the OLS ones. However, the Durbin-Wu-Hausman test shows that we cannot reject the null hypothesis of the OLS estimator yielding consistent estimates; we thus conclude that there are no statistically significant differences between the OLS and IV estimates. Under the assumption that our instrument is indeed exogenous and given that the OLS estimator is more efficient, we consider OLS our preferred estimation method.

Table 6: Regression results / Instrumental variables

Dependent variable:	log(exports)			
	All countries		Non-EU countries	
	1st stage	2nd stage	1st stage	2nd stage
	(1)	(2)	(3)	(4)
Harmonization neighbors	0.25111***		0.24708***	
	[0.00415]		[0.00599]	
Harmonization		0.01396**		0.05275***
		[0.00707]		[0.01634]
Observations	5860748	5860748	1792985	1792985
F-statistic	3654		1704	
Exporter-product-time FE	yes	yes	yes	yes
Importer-product-time FE	yes	yes	yes	yes
Exporter-importer-product FE	yes	yes	yes	yes
Exporter-importer-time FE	yes	yes	yes	yes

Notes: The first-stage of our instrumental variables regression regresses the neighboring countries harmonization indicator on the home country's harmonization indicator. The second stage regresses bilateral product-level exports on the instrumented harmonization indicator. Fixed effects (FE) are included as described in the regression specification 18. Standard errors are clustered at the exporter-product-level and are reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

6.5 Additional robustness

We briefly summarize additional robustness checks reported in Appendix F below. First, we include a flexible difference-in-difference specification that allows for a non-constant marginal effect that varies with treatment intensity. The results show the marginal effect of harmonization events is linear in the number of harmonization events (up to 12-13 events). For a higher number of harmonization events, the marginal effect remains positive but confidence intervals increase significantly. Second, we estimate our baseline specification using our concordance table obtained via keyword-matching techniques. The results are comparable to the baseline estimates reported in Table 2. Third, we address the problem of zeros in the gravity equation and estimate the baseline specification using the PPML approach advocated by Silva and Tenreyro (2006). The estimated effects for standard harmonization are positive, statistically significant and the coefficients are almost identical to our baseline results.

Overall, the evidence presented in this section suggests that our results are robust to endogeneity concerns and model specification. We can exclude that the results are driven by the size effect of large and growing trade flows. Including pre-trends into the analysis shows that these are not significant. Finally, addressing potential endogeneity bias with

IV techniques and using a measure of largely exogenous, supranational standards yields results that are consistent with the baseline approach.

7 Firm-level evidence

Our product-level results show a significant increase in trade following the introduction of a harmonized standard. This product-level effect corresponds to an average treatment effect consisting of the share of firms that choose to produce in accordance with the harmonized standard times their increase in export sales. Conditional on choosing to adopt the standard, the marginal effect of harmonized standards on export sales of firms should be larger than on the product level. According to our theoretical model, only the most productive firms choose to produce in accordance with the harmonized standard and experience an increase in export sales.

To investigate the presence of this selection effect, we use firm-level data obtained from French customs declarations. A limitation is that the data does not allow us to identify the firms that choose to produce in accordance with the harmonized standard. For this reason, we exploit the predictions of the model and test whether the marginal effect of standard harmonization varies with firm size, trade costs as well as destination country characteristics. In addition, we investigate whether harmonized standards generate consumer demand by exploiting product and standard characteristics that are indicative of stronger demand effects.

7.1 Gravity decomposition

As a first step, we decompose French bilateral product-level trade flows in equation 15 into an extensive and intensive margin. Following Buono and Lalanne (2012), we define the extensive margin ($\log(M_{ijkt})$) as the log of number of firms that export a 4-digit HS category k to destination j in year t and the intensive margin ($\log(\bar{x}_{ijkt})$) as the log of average firm-level sales per 4-digit HS product.[35] Given these definitions, the log of the bilateral product-level trade ($\log(X_{ijkt})$) is simply the sum of the intensive and extensive margin.

Next, we match our standard harmonization database at the HS 4-digit level with French firm-level data for the period 1995–2014. We have information on the euro value of exports for each firm and restrict the sample to the 25 importing countries in our standard database. Column (1) in Table 7 shows that standard harmonization increases French exports by 1.8%, which is higher than in our baseline product-level regression in Table 2. The decomposition shows that standard harmonization allows exporters to expand their sales (positive effect on the intensive margin) and there is no significant effect on entry.[36]

[35] When we aggregate the firm-level export sales to the 4-digit product-level, we can compare French exports sales derived from the firm-level dataset to the product-level trade flows provided by UN Comtrade (the basis for our product-level analysis). The correlation between these two datasets is 0.99.

[36] This is consistent with the predictions from the model under the assumption that the effect of standard harmonization on the exporter entry cut-off (equation 14) through the importer-price index is small.

Table 7: Regression results / Gravity equation

Dependent variable:	log(exports) (1)	Extensive margin (2)	Intensive margin (3)
Harm.	0.01807*** [0.00619]	0.00301 [0.00196]	0.01506*** [0.00554]
Observations	300457	300457	300457
R^2	0.88	0.97	0.80
Adjusted R^2	0.87	0.96	0.78
Exporter-product-time FE	yes	yes	yes
Exporter-importer-time FE	yes	yes	yes
Exporter-importer-product FE	yes	yes	yes

Notes: Regression of the respective dependent variable (designated in column headers) on the harmonization indicator. Fixed effects (FE) are included as described in the table. Standard errors are clustered at the 4-digit HS product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

To provide further supportive evidence for these results, we bring our analysis to the firm-level and estimate the following regression specification

$$Y_{fjnt} = \beta h_{jnt} + f_{fjn} + f_{fjt} + \varepsilon_{fjnt}, \tag{23}$$

where f designates a firm, n the 6-digit HS product-level, j the importing country and t the year of observation. We include controls for any unobserved effects at the firm-importer-product level (f_{fjn}) as well as at the firm-importer-year level (f_{fjt}).[37] We measure the extensive margin ("export status") by specifying a dummy variable Y_{fjnt} that equals one if the firm has positive exports and zero otherwise. The second variable consists of total export sales per firm f in a 6-digit HS category n to importing country j in year t (in logs), which we further decompose into prices (proxied by unit values in terms of kilograms or units shipped) and quantities; both variables are included in logs.

The results shown in Table 8 are similar to the results obtained from the gravity decomposition (see Table 7). Standard harmonization is associated with an increase of total sales (column (2)) of 0.69% and of 0.72% when focusing on the sample of firms for which we have unit value and quantity data (column (3)). Concerning the extensive margin, we find no evidence of new entry (see column (1)). Column (4) and column (5) split the log of firm sales into the log price (unit values) and the log quantity component. Table 8 shows that firms sell larger volumes despite charging higher prices. These results favor the interpretation that standard harmonization increases product demand as predicted by the model.

See Appendix B for a discussion.

[37] We also ran our firm-level regressions with a less demanding fixed-effects set-up as in Fontagné et al. (2015) by including HS2-destination-year ($f_{HS2,j,t}$) and firm (f_f) fixed effects. In this case, all coefficients for export status, total sales as well as prices and quantities are positive and significant.

Table 8: Regression results / Firm-level data

Dependent variable:	Export status (1)	log(export sales) (2)	log(export sales) (3)	log(price) (4)	log(quantity) (5)
Harm.	0.00076	0.00686***	0.00723***	0.00353**	0.00370*
	[0.00050]	[0.00254]	[0.00262]	[0.00146]	[0.00212]
Observations	19800340	8355360	7898075	7898075	7898075
R^2	0.62	0.85	0.85	0.90	0.88
Adjusted R^2	0.53	0.80	0.79	0.86	0.84
Firm-product-time FE	yes	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes	yes

Notes: Regression of the respective dependent variable in logs (designated in column headers) on the harmonization indicator. Columns (3)–(5) are based on a regression sample containing only observations for which information on quantities is available. Fixed effects (FE) are included as described in regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

7.2 Evidence on the selection effect

The key implication of our model is that harmonization generates a selection effect, which incentivizes only a subset of firms (i.e. the most productive and largest ones) to invest in the product standard and to increase their sales. Accordingly, the positive effect of standard harmonization should vary with the exporters' size distribution. We use quartile-based bins as in Lileeva and Trefler (2010) and group each firm into one of the four bins. To determine the size cut-off for each bin, we sum export sales across all markets and products for each firm and calculate the size quartiles from the resulting sales distribution. We then estimate the effect of harmonized standard releases for each size bin separately.[38]

Table 9 shows that standard harmonization has a positive effect in the bin with the largest set of firms (fourth quartile) only. Comparing standardized versus non-standardized products, the estimated coefficient implies that firms exporting in standardized product categories increase their sales by 1.1%. For all other quartiles, we do not find any significant differences in firm export sales across the different product groups.

[38] An alternative specification with interaction terms of the harmonization dummy and each size bin dummy leads to similar results. Results based on ten bins rather than four size bins show that only firms in the top three bins experience higher sales. In an additional robustness test, we restrict the sample to multi-product firms and test for differences in export sales of products with harmonized standards and products without harmonized standards within the same firm. The results in Table 20 in Appendix F are very similar to Tables 8 and 9.

Table 9: Regression results / Firm-size distribution

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm.	-0.00210	0.00470	0.00505	0.01065***
	[0.00493]	[0.00385]	[0.00351]	[0.00273]
Observations	1232275	1977829	2326224	2600890
R^2	0.84	0.85	0.86	0.85
Adjusted R^2	0.73	0.77	0.80	0.81
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

Notes: Regression of the log of export sales on the harmonization indicator for different firm-size bins. Column (1) contains the first quartile of firms with the smallest size. Column (2) contains firms in the second and column (3) in the third size quartile. Column (4) contains the fourth quartile with the largest 25% of exporting firms. Fixed effects (FE) are included as described in regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

In addition to size, the selection effect should vary with bilateral and destination country characteristics. As equation 14 shows, the effect should be higher in larger destination markets with lower bilateral trade costs. Due to cost complementarities, common harmonized standards accredited by many countries should induce more firms to adopt the standard and increase the positive effects. In Table 10 panel (a), we interact the harmonization dummy with the log of nominal GDP in the destination country at the beginning of the sample period in the year 1995 (proxy for destination market size) as well as with the log of the bilateral distance between France and the destination country (to proxy for bilateral trade costs).[39] In panel (b) we interact the harmonization dummy with the number of countries whose SSOs release a harmonized standard along with France. The results show that both destination market size and the number of harmonizing countries increase the positive effect of harmonization by inducing more firms to adopt the standard (the interaction term is now positive for the third and the fourth quartile of the size distribution, instead of just the fourth quartile). At the same time, this positive effect decreases with distance. For firms in other size-quartiles, the results are insignificant.

Our results on the size-dependent selection effects also inform on the regulatory nature of the product standards in our database. As discussed in Section 3, mandatory standards constrain all firms to produce according to the standard, requiring them to pay the associated sunk investment costs. This cost structure implies that average production costs increase more for smaller firms and should affect them the most. Given that the marginal exporter tends to be a small firm, we would expect that regulatory standards lead to changes in the number of exporters (i.e. extensive margin) and to larger changes in export sales for firms in lower quartiles of the size-distribution. As the results in Tables 8 and 9 show, we do not find empirical support for these predictions. This supports the assumption that standards in our database are primarily voluntary.

[39] Using the log of a country's population in 1995 as an alternative measure of market size leads to very similar results.

Table 10: Regression results / Size quartiles and destination characteristics

(a) Market size and trade costs

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm.	0.00021	0.00192	0.00124	0.00893***
	[0.00566]	[0.00434]	[0.00405]	[0.00309]
Harm. x log(GDP)	0.00002	0.00004	0.00014***	0.00023***
	[0.00004]	[0.00003]	[0.00003]	[0.00003]
Harm. x log(distance)	-0.00026	0.00016	0.00003	-0.00028***
	[0.00024]	[0.00013]	[0.00011]	[0.00009]
Observations	1232275	1977829	2326224	2600890
R^2	0.84	0.85	0.86	0.85
Adjusted R^2	0.73	0.77	0.80	0.81
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

(b) Number of countries and trade costs

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm.	0.00030	0.00227	0.00289	0.01160***
	[0.00561]	[0.00431]	[0.00402]	[0.00304]
Harm. x Nr. of countries harmonizing	0.00027	0.00044	0.00162***	0.00265***
	[0.00046]	[0.00034]	[0.00030]	[0.00037]
Harm. x log(distance)	-0.00028	0.00013	-0.00009	-0.00051***
	[0.00024]	[0.00014]	[0.00012]	[0.00010]
Observations	1232275	1977829	2326224	2600890
R^2	0.84	0.85	0.86	0.85
Adjusted R^2	0.73	0.77	0.80	0.81
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

Notes: Regression of the log of export sales on harmonization indicator for different firm-size bins. Columns (1) contains the first quartile of firms with the smallest size. Column (2) contains firm in the second and column (3) in the third size-quartile. Column (4) contains the fourth quartile with the largest 25% of exporting firms. Fixed effects (FE) are included as described in the regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

7.3 Evidence on demand effects

In the theoretical framework, we argue that the main channel through which standardization materializes into larger trade flows is higher consumer demand. Standards can increase product quality, create network effects, ensure interoperability and reduce information asymmetries; the use of a common standard renders extensive product descriptions obsolete, as producers can simply refer to the standard to inform importers of the properties of their product. Similarly, standards may allow consumers to infer the quality of a product via certification and labeling: it is easier for producers of high-quality goods to market their products. The resulting demand effects are captured by a shift in demand (respectively z_{jk} or z_k) towards these standardized varieties. If demand effects indeed work via quality increases, reductions of information asymmetries, interoperability and network effects, we expect them to be larger for highly differentiated products. To address this issue, we use product classifications by Rauch (1999) and Khandelwal (2010) to categorize them into differentiated and homogeneous products.

The Rauch (1999) classification categorizes goods according to three types: differentiated products, products traded on organized exchanges, or products that have a reference price. We combine the latter two into one category and refer to them as homogeneous products. The other product classification is based on the "quality ladder" index from Khandelwal (2010). The "quality ladder" index measures the range of qualities within a product category and is defined as the difference between the highest and lowest quality level. As Khandelwal (2010) shows, a higher index is associated with a higher degree of differentiation.

We interact these indicators with our harmonization indicator and estimate the following specification for each size-bin and differentiation indicator (DI_k) in our firm-level dataset:

$$Y_{fjnt} = \beta_0 h_{ijkt} + \beta_1 h_{ijkt} \text{DI}_k + f_{fjn} + f_{fjt} + \varepsilon_{fjnt}, \tag{24}$$

The Rauch differentiation indicator $\text{DI}_k = \text{Rauch}_k$ is a dummy indicator that takes the value of one if product k is a differentiated product as defined by Rauch (1999) and the quality ladder indicator $\text{DI}_k = \text{Qladder}_k$ is a dummy indicator that equals one for a product k if the product-specific quality ladder index from Khandelwal (2010) is above the median index.[40]

Table 11 shows that the effect of harmonized standard releases is mainly present in differentiated products. The positive coefficient for the interaction term with the Rauch dummy for the third and fourth quartile in panel (a) implies that standard harmonization increases international trade only for differentiated products, while the insignificant effect for the harmonization variable suggests no effect for homogeneous products. Similarly, panel (b) shows that the positive effect of standard harmonization extends also to the third quartile for product categories with a longer than median quality ladder.

Taken together, these results present suggestive evidence that standards increase demand through an increase in compatibility, improvements in product quality or a reduction of information asymmetries. This interpretation is similar to Rauch (1999) or more recently Brynjolfsson et al. (2019), who show that a reduction in search costs, as in the case of language barriers, increases trade flows, and that this effect is even more pronounced for differentiated products. On the aggregate level, these effects are sizeable. When running the same regressions on the product-level, the introduction of harmonized standards raises trade for differentiated products by respectively 1.9% (Rauch dummy) and 2.4% (Qladder dummy), substantially higher than the baseline estimate of 0.59%.[41]

[40] In an alternative specification, we use the product-specific quality ladder index rather than a dummy variable and experiment with using the elasticity of substitution estimates from Soderbery (2018) as proxy for the degree of product differentiation. Both modifications lead to similar results.

[41] Detailed results are available upon request.

Table 11: Regression results / Differentiated products

(a) Rauch specification

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm.	-0.00139	0.00313	-0.00082	0.00049
	[0.00634]	[0.00468]	[0.00415]	[0.00409]
Harm. x Rauch	-0.00074	0.00172	0.00663**	0.01091***
	[0.00402]	[0.00303]	[0.00283]	[0.00325]
Observations	1232275	1977829	2326224	2600890
R^2	0.84	0.85	0.86	0.85
Adjusted R^2	0.73	0.77	0.80	0.81
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

(b) Quality ladder specification

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm.	-0.00417	0.00331	0.00267	0.00882***
	[0.00527]	[0.00401]	[0.00359]	[0.00290]
Harm. x ladder	0.00281	0.00201	0.00380**	0.00310**
	[0.00248]	[0.00163]	[0.00148]	[0.00144]
Observations	1232275	1977829	2326224	2600890
R^2	0.84	0.85	0.86	0.85
Adjusted R^2	0.73	0.77	0.80	0.81
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

Notes: Regression of the log of export sales on the harmonization indicator for different firm-size bins. Column (1) contains the first quartile of firms with the smallest size. Column (2) contains firm in the second and column (3) in the third size-quartile. Column (4) contains the fourth quartile with the largest 25% of exporting firms. Fixed effects (FE) are included as described in regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

7.4 Evidence on standardization benefits

Our database covers a wide range of standards, both in terms of the products affected as well as the purposes of the standard. While the above section shows that the demand effect is stronger for products for which standardization is particularly useful, this section provides evidence on the type of standardization benefits that generate these demand effects. We use keywords of the bibliographical information contained in our standards database to infer the content and purpose of a standard. We consider the following set of keywords: "testing", "quality", "safety", "environment", "compatibility", "terminology", "network", "components" and "measurement". Standards containing the keywords "environment", "compatibility", "network" and "components" proxy for network effects and interoperability, while the keywords "testing", "quality", "safety", "terminology" and "measurement" are more likely to capture information asymmetries and quality. In the empirical specification, we estimate the effect of harmonized standards for each keyword and each firm-size bin of our firm-level dataset separately.

Table 12: Regression results / Firm-level results per quartile and keyword

(a) Keywords (KW) capturing quality and information asymmetries

Dependent variable:	log(export sales)			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm. KW(Testing)	0.00075	0.00536	0.00126	0.00795**
	[0.00651]	[0.00499]	[0.00432]	[0.00346]
Harm. KW(Quality)	0.00668	0.00741	0.00223	0.01170***
	[0.00564]	[0.00509]	[0.00460]	[0.00389]
Harm. KW(Safety)	0.00425	0.00720	-0.00301	0.01215***
	[0.00607]	[0.00473]	[0.00413]	[0.00342]
Harm. KW(Terminology)	0.00080	0.00770	0.00166	0.01273***
	[0.00572]	[0.00476]	[0.00400]	[0.00339]
Harm. KW(Measurement)	0.00816	0.00958**	0.00753*	0.01250***
	[0.00602]	[0.00485]	[0.00400]	[0.00365]
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

(b) Keywords (KW) capturing interoperability and network effects

Dependent variable:	log(export sales			
	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
Harm. KW(Environment)	0.00979	0.00033	-0.00542	0.00497
	[0.00829]	[0.00714]	[0.00549]	[0.00417]
Harm. KW(Compatibility)	0.01121	0.00949	0.00754	-0.00516
	[0.01151]	[0.00814]	[0.00717]	[0.00552]
Harm. KW(Network)	-0.00801	0.00180	0.01531	0.00330
	[0.01524]	[0.01160]	[0.01104]	[0.00751]
Harm. KW(Components)	0.00689	0.00868*	0.01311***	0.01321***
	[0.00581]	[0.00475]	[0.00413]	[0.00375]
Firm-product-time FE	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes

Notes: Separate regressions of the log of export sales on the harmonization indicator for each keyword for different firm-size bins. Column (1) contains the first quartile of firms with the smallest size. Column (2) contains firms in the second and column (3) in the third size-quartile. Column (4) contains the fourth quartile with the largest 25% of exporting firms. Fixed effects (FE) are included as described in regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

Table 12 shows the results. Standards that contain keywords related to information asymmetries and quality ("testing", "quality", "safety", "terminology" and "measurement") increase trade for larger firms (i.e. those in the fourth size quartile) exporting these products. Among the keywords that address interoperability and network effects only the standards containing the keyword "components" lead to significant effects. For all other keywords, we do not find any significant effect. These results suggest that standards increase product demand predominantly by signaling higher quality and safety as well as by reducing information asymmetries about product attributes through common terminology and measurement. The reduction in information asymmetries could also explain the positive effects for the keyword "components" if harmonized standards define product characteristics that facilitate the access to foreign inputs.

Taken together, our firm-level results support the presence of our model's size-dependent selection effect. Due to the presence of sunk investment costs not all firms can take advantage of the positive demand effects from harmonized standards. According to our estimates, only firms in the upper quartile choose to produce in accordance with the harmonized standard. These firms benefit from higher product demand that allows them to sell larger volumes.

8 Conclusion

Data limitations have prevented a thorough empirical analysis of the economic effects of standardization and cross-border harmonization efforts. This paper is a first attempt to fill this gap by providing a novel database that tracks national and international product standards and quantifies their impact on international trade. Each year during the period from 1995 to 2014, Standard Setting Organizations (SSOs) released harmonized standards that affected more than 40% of globally traded products. Our results suggest that they are an effective policy tool in facilitating common product specifications across countries and in fostering trade integration. According to our estimates, the release of harmonized products standards can explain up to 13% of the growth in global trade during our sample period.

While our results show that cross-country standardization efforts are helping firms market their products abroad, important questions remain with respect to the optimality of the standard-setting process. An important finding of the paper is that predominantly large firms benefit from standard harmonization. From a competition policy point of view, this raises concerns if standards require the use of patents developed by these firms and necessitate royalty payments (see, for example, Schmalensee, 2009, Llanes and Poblete, 2014 and Lerner and Tirole, 2015 for a recent discussion). The fact that large firms profit disproportionately from the standard-setting process implies that they have strong incentives to lobby governments in making these standards regulatory, for example within a preferential trade agreement.[42] This would lower consumer welfare, see Maggi and Ossa (2020) for a recent discussion on producer lobbying and the inclusion of regulatory product standards within preferential trade agreements.

Analyzing the effects of standards on market structure and investigating which factors contribute to their development and accreditation in the first place are important avenues for future research.

[42] As McDaniels et al. (2018) document, more and more preferential trade agreements explicitly refer to voluntary product standards making them de facto legally binding.

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Online Appendix

A Model

Firm profits and sales

Firms can produce a standardized or a non-standardized variety. Firm-level variables that are specific to firms producing the standardized variety are denoted by the superscript z. Throughout, we assume that the production of a standardized variety is associated with sunk fixed costs $a(z_{ijk})$.

Firms producing the non-standardized variety. Profits of firms that decide to produce a non-standardized variety are given by

$$\pi_{ijk}(\varphi) = \frac{x_{ijk}(\varphi)}{\sigma_k} - w_i f_{ijk}, \tag{25}$$

where sales are given by

$$x_{ijk}(\varphi) = A_{jk} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk}}{\varphi} \right)^{1-\sigma_k}, \tag{26}$$

where $A_{jk} = P_{jk}^{\sigma_k - 1} X_{jk}$.

Firms producing the standardized variety. Profits of firms producing a standardized good with productivity φ from country i selling to country j and choosing the price optimally are given by

$$\pi_{ijk}^n(\varphi) = \frac{x_{ijk}^n(\varphi)}{\sigma_k} - w_i f_{ijk} - w_i a(z_{ijk}), \tag{27}$$

where sales are given by

$$x_{ijk}^n(\varphi) = A_{jk} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk}}{\varphi} \right)^{1-\sigma_k} z_{ijk}^{(\sigma_k - 1)(1-t_k)}, \tag{28}$$

Productivity cut-offs for a national standard

There are two productivity cut-offs. The cut-off $\bar{\varphi}_{ijk}^n$ is given by the firm that is indifferent between producing the standardized and the non-standardized variety.

$$\begin{aligned} &\frac{A_{jk}}{\sigma_k} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk}}{\varphi} \right)^{1-\sigma_k} z_{jk}^{(\sigma_k - 1)(1-t_k)} - w_i (f_{ijk} + a(z_{jk})) \\ =&\frac{A_{jk}}{\sigma_k} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i \tau_{ijk}}{\varphi} \right)^{1-\sigma_k} - w_i f_{ijk} \end{aligned} \tag{29}$$

The resulting productivity cut-off to produce standardized varieties is

$$\bar{\varphi}_{ijk}^{n} = \left(\frac{\sigma_k w_i a(z_{jk})}{s(z_{jk}) A_{jk}} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk}. \tag{30}$$

where $s(z_{jk}) = z_{jk}^{(\sigma_k - 1)(1 - t_k)} - 1$. In addition, there is a cut-off productivity ($\bar{\varphi}_{ijk}$) below which firms will not sell in country j because the potential revenues cannot cover production and fixed costs of exporting to j. This cut-off is obtained by setting the profits of a non-standardized variety equal to zero:

$$\bar{\varphi}_{ijk} = \left(\frac{\sigma_k w_i f_{ijk}}{A_{jk}} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \tag{31}$$

Productivity cut-offs for a harmonized standard

Firms have cost complementarities and need to pay the sunk investment cost for the harmonized standard $a(z_k)$ in one market only. The cut-off $\bar{\varphi}_{ijk}^{h}$ is given by the firm that is indifferent between producing the standardized and the non-standardized variety

$$\begin{aligned} &\frac{A_{ik} + A_{jk} \tau_{ijk}^{1-\sigma_k}}{\sigma_k} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i}{\varphi} \right)^{1-\sigma_k} z_k^{(\sigma_k - 1)(1 - t_k)} - w_i (f_{iik} + f_{ijk} + a(z_k)) \\ =&\frac{A_{ik} + A_{jk} \tau_{ijk}^{1-\sigma_k}}{\sigma_k} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i}{\varphi} \right)^{1-\sigma_k} - w_i (f_{iik} + f_{ijk}) \end{aligned} \tag{32}$$

and the associated productivity cut-off equals:

$$\bar{\varphi}_{ijk}^{h} = \left(\frac{\sigma_k w_i a(z_k)}{s(z_k) \left(A_{ik} + A_{jk} \tau_{ijk}^{1-\sigma_k} \right)} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k w_i}{\sigma_k - 1} \tag{33}$$

where $s(z_k) = z_k^{(\sigma_k - 1)(1 - t_k)} - 1$.

Implied assumptions in order to have partitioning

As in Melitz (2003), we assume that the values for fixed and marginal costs are such that there is partitioning into exporters and non-exporters. In particular, this condition can be derived as follows. Let $\bar{\varphi}_{iik}$ denote the domestic production cut-off derived from the zero profit condition for domestic sales:

$$\pi_{iik}(\bar{\varphi}_{iik}) = \frac{1}{\sigma_k} A_{ik} \left(\frac{\sigma_k}{\sigma_k - 1} \frac{w_i}{\bar{\varphi}_{iik}} \right)^{1-\sigma_k} - w_i f_{iik} = 0 \tag{34}$$

$$\bar{\varphi}_{iik} = \frac{\sigma_k w_i}{\sigma_k - 1} \left(\frac{w_i f_{iik}}{A_{ik}} \right)^{\frac{1}{\sigma_k - 1}} \tag{35}$$

Partitioning into exporters and non-exporters occurs if:

$$\pi_{iik}(\bar{\varphi}_{iik}) < 0 \tag{36}$$

$$f_{iik}\frac{A_{jk}}{A_{ik}} < f_{ijk}\tau_{ijk}^{\sigma_k - 1} \tag{37}$$

The condition for partitioning into exporters that produce according to the standard z_{jk} or not can be derived similarly:

$$\pi_{ijk}^{n}(\bar{\varphi}_{ijk}) < 0 \tag{38}$$

$$f_{ijk}s(z_{jk}) < a(z_{jk}) \tag{39}$$

This condition implies that the ratio of sunk investment costs and fixed costs of exporting is such that only high-productivity exporters are able to adapt their product to the foreign standard.

Gravity equation for national standards

We can write total bilateral export sales of country i to country j

$$X_{ijk} = \int_{\omega \in \Omega_{ij}} x_{ijk}(\omega) dG(\omega), \tag{40}$$

as the sum of the sales of firms that produce the standardized varieties (firms with productivity in the interval $\bar{\varphi}_{ijk}^{n} < \varphi < \infty$) and firms that produce the non-standardized variety (firms with productivity in the interval $\bar{\varphi}_{ijk} < \varphi < \bar{\varphi}_{ijk}^{n}$):

$$\begin{aligned} X_{ijk} = & A_{jk}\left(\frac{\sigma_k w_i \tau_{ijk}}{\sigma_k - 1}\right)^{1-\sigma_k} M_{ijk} \\ & \left(\frac{\tilde{M}_{ijk}}{M_{ijk}}\left(\tilde{\varphi}_{ijk}\right)^{\sigma_k - 1} + \frac{\tilde{M}_{ijk}^{n}}{M_{ijk}} z_{ijk}^{(\sigma_k - 1)(1-t_k)}\left(\tilde{\varphi}_{ijk}^{n}\right)^{\sigma_k - 1}\right), \end{aligned} \tag{41}$$

where $\tilde{M}_{ijk}$ is the number of firms producing the non-standardized varieties with average productivity $\tilde{\varphi}_{ijk}$ and $\tilde{M}_{ijk}^{n}$ is the number of firms producing the standardized varieties with average productivity $\tilde{\varphi}_{ijk}^{n}$.

Average productivity for firms producing the non-standardized varieties is defined as

$$\tilde{\varphi}_{ijk} = \left(\int_{\bar{\varphi}_{ijk}}^{\bar{\varphi}_{ijk}^{n}} \varphi^{\sigma_k - 1} d\frac{G(\varphi)}{G(\bar{\varphi}_{ijk}^{n}) - G(\bar{\varphi}_{ijk})}\right)^{\frac{1}{\sigma_k - 1}}, \tag{42}$$

which we can simplify to

$$\begin{aligned} \left(\tilde{\varphi}_{ijk}\right)^{\sigma_k - 1} = & \left[\left(\bar{\varphi}_{ijk}^{n}\right)^{-\xi_k} - \left(\bar{\varphi}_{ijk}\right)^{-\xi_k}\right]^{-1} \frac{\xi_k}{\xi_k - (\sigma_k - 1)} \\ & \left[\left(\bar{\varphi}_{ijk}^{n}\right)^{-\xi_k + (\sigma_k - 1)} - \left(\bar{\varphi}_{ijk}\right)^{-\xi_k + (\sigma_k - 1)}\right]. \end{aligned} \tag{43}$$

Using the fact that we can express the cut-offs in terms of the share of exporters producing the standardized variety $\delta_{ijk} = \bar{\varphi}^n_{ijk}/\bar{\varphi}_{ijk}$, we get

$$(\tilde{\varphi}_{ijk})^{\sigma_k-1} = (\bar{\varphi}_{ijk})^{\sigma_k-1} \frac{\xi_k}{\xi_k - (\sigma_k - 1)} \frac{1 - (\delta_{ijk})^{-\xi_k+(\sigma_k-1)}}{1 - (\delta_{ijk})^{-\xi_k}} \tag{44}$$

Similarly, the average productivity for firms producing the standardized varieties is defined as:

$$\tilde{\varphi}^n_{ijk} = \left(\int_{\bar{\varphi}^n_{ijk}}^{\infty} \varphi^{\sigma_k-1} d \frac{G(\varphi)}{1 - G(\bar{\varphi}^n_{ijk})} \right)^{\frac{1}{\sigma_k-1}} \tag{45}$$

Plugging in the average productivities and substituting $\tilde{M}^n_{ijk}/M_{ijk} = (\delta_{ijk})^{-\xi_k}$, the gravity equation with the extensive and intensive margin is written as

$$X^n_{ijk} = \underbrace{\left(\frac{A_{jk}}{\sigma_k f_{ijk}} \right)^{\frac{\xi_k}{(\sigma_k-1)}} \left(\frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \right)^{-\xi_k} M_{ik}}_{\text{Extensive margin}} \underbrace{\Gamma_k f_{ijk} \left(1 + \Delta^n_{ijk} s(z_{jk})\right)}_{\text{Intensive margin}} \tag{46}$$

where the weight is defined as: $\Delta^n_{ijk} = \delta^{-\xi_k+(\sigma_k-1)}_{ijk} = \left(\frac{s(z_{jk}) f_{ijk}}{a(z_{jk})} \right)^{\frac{\xi_k}{\sigma_k-1}-1}$ and $\Gamma_k = \frac{\xi_k \sigma_k}{\xi_k - (\sigma_k-1)}$.

Gravity equation for harmonized standards

We can follow the same steps as above. The difference is that the ratio of exporters producing the harmonized standardized variety is now defined as:

$$\frac{\bar{\varphi}^h_{ijk}}{\bar{\varphi}_{ijk}} = \left(\frac{a(z_k)}{s(z_k) \left(A_{ik} + A_{jk} \tau^{1-\sigma_k}_{ijk} \right)} \frac{A_{jk} \tau^{1-\sigma_k}_{ijk}}{f_{ijk}} \right)^{\frac{1}{\sigma_k-1}} \tag{47}$$

The corresponding gravity equation with the extensive and intensive margin is written as

$$X^h_{ijk} = \underbrace{\left(\frac{A_{jk}}{\sigma_k f_{ijk}} \right)^{\frac{\xi_k}{(\sigma_k-1)}} \left(\frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} \right)^{-\xi_k} M_{ik}}_{\text{Extensive margin}} \underbrace{\Gamma_k w_i f_{ijk} \left(1 + \Delta^h_{ijk} s(z_k)\right)}_{\text{Intensive margin}} \tag{48}$$

where the term $\Delta^h_{ijk} = \left(\frac{s(z_k)\left(A_{ik} + A_{jk} \tau^{1-\sigma_k}_{ijk}\right)}{a(z_k)} \frac{f_{ijk}}{A_{jk} \tau^{1-\sigma_k}_{ijk}} \right)^{\frac{\xi_k}{\sigma_k-1}-1}$ captures the share of exporters that produce according to the product standard.

Cost complementarity and demand effect

Comparing the situation of harmonized and national standards, we can separate the two described effects:

$$X_{ijk}^h - X_{ijk}^n = \left\{ \underbrace{\left(\lambda^h - \lambda^n\right) s(z_{jk})^{\frac{\xi_k}{\sigma_k - 1}}}_{\text{cost complementarity effect}} + \underbrace{\lambda^h \left(s(z_k)^{\frac{\xi_k}{\sigma_k - 1}} - s(z_{jk})^{\frac{\xi_k}{\sigma_k - 1}} \right)}_{\text{demand effect}} \right\} \tag{49}$$

where

$$\lambda^h = \left(\frac{f_{ijk}}{a(z_k)} \frac{\left(A_{ik} + A_{jk}\tau_{ijk}^{1-\sigma_k}\right)}{A_{jk}\tau_{ijk}^{1-\sigma_k}} \right)^{\frac{\xi_k}{\sigma_k - 1} - 1} \tag{50}$$

$$\lambda^n = \left(\frac{f_{ijk}}{a(z_{jk})} \right)^{\frac{\xi_k}{\sigma_k - 1} - 1} \tag{51}$$

summarize cost and market size parameters. λ^h is larger than λ^n due the second term in equation 50 being larger than one. We assume that fixed investment costs for z_k and z_{jk} are the same: $a(z_k) = a(z_{jk})$.

B Consumer welfare with harmonized standards in a 2-sector version

We consider a 2-country 2-sector economy version of our baseline model. The specification of preferences, production, entry and the choice of adopting a standard are the same. Recall the cutoffs for domestic producers, exporters of the non-standardized variety and the standardized variety as given in equations 35, 9 and 14:

$$\bar{\varphi}_{iik} = \frac{\sigma_k w_i}{\sigma_k - 1} \left(\frac{w_i f_{iik}}{A_{ik}} \right)^{\frac{1}{\sigma_k - 1}} \tag{52}$$

$$\bar{\varphi}_{ijk} = \left(\frac{\sigma_k w_i f_{ijk}}{A_{jk}} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k}{\sigma_k - 1} w_i \tau_{ijk} = \frac{\bar{\varphi}_{iik}}{\Delta^x} \tag{53}$$

$$\bar{\varphi}^h_{ijk} = \left(\frac{\sigma_k w_i a(z_k)}{s(z_k) \left(A_{ik} + A_{jk} \tau_{ijk}^{1-\sigma_k} \right)} \right)^{\frac{1}{\sigma_k - 1}} \frac{\sigma_k w_i}{\sigma_k - 1} = \frac{\bar{\varphi}_{ijk}}{\Delta^z} \tag{54}$$

Δ^x designates the ratio between the domestic cutoff $\bar{\varphi}_{iik}$ and the export cutoff $\bar{\varphi}_{ijk}$ and Δ^z the ratio between the cutoffs for non-standardizers and standardizers.

Free entry decision

The free-entry assumption implies that the expected profits from entering the economy must equal the fixed cost to enter:

$$(1 - G(\bar{\varphi_{iik}}))\tilde{\pi}_{ik} = w_i f^e \tag{55}$$

The average profit is defined as the share of profits from firms selling in the domestic market, the share of profits from firms that export the non-standardized variety and the share of firms that export the standardized variety.

$$\begin{aligned} \tilde{\pi}_{ik} = & \left(1 - \Delta^x \Delta^z\right) \tilde{\pi}_{iik}(\tilde{\varphi}_{iik}) + \Delta^x \Delta^z \tilde{\pi}^h_{iik}(\tilde{\varphi}^h_{ijk}) \\ & + \Delta^x \left[\left(1 - \Delta^z\right) \tilde{\pi}_{ijk}(\tilde{\varphi}_{ijk}) + \Delta^z \tilde{\pi}^h_{ijk}(\tilde{\varphi}^h_{ijk}) \right] \end{aligned} \tag{56}$$

Sectoral number of firms

The mass of producing firms in a given sector k (M_k) equals the mass of entrants (M^e) times the probability of successful entry into the industry ($1 - G(\bar{\varphi}_{iik})$). This mass of producing firms also equals sectoral revenue (X_k) divided by average firm revenue in the sector ($\tilde{x_k}$):

$$M^e(1 - G(\bar{\varphi}_{iik})) = M_k \tag{57}$$

Using the definition of sectoral revenues

$$X_k = M_k \tilde{x}_k \tag{58}$$

and the definition of average revenues (which is similar to the definition of average profits in equation 56 plus the fixed and sunk investment costs). We can simplify and express the number of firms entering by:

$$M^e = \frac{X_k}{\sigma_k \left[f^e + \left(f_{iik} + \Delta^x f_{ijk} + \Delta^x \Delta^z a(z_k)\right)\left(1 - G(\bar{\varphi}_{iik})\right)\right]} \tag{59}$$

We can express the sectoral demand as a function of aggregate demand ($X_k = (P_k/P)^{1-\gamma} X$) and use the equilibrium condition that total revenues have to equal total income $X = wL$. Due to symmetry, we can normalize the wage to one ($w = 1$) and write the number of firms entering sector k as follows:

$$M_k = \frac{\left(\frac{P_k}{P}\right)^{1-\gamma} L}{\sigma_k \left(\frac{f^e}{(1-G(\bar{\varphi}_{iik}))} + \left(f_{iik} + \Delta^x f_{ijk} + \Delta^x \Delta^z a(z_k)\right)\right)} \tag{60}$$

Using the definition of the sectoral CES price index, we get an alternative equation that determines the number of firms producing in industry k. The sectoral price index is defined by the average prices of the share of domestic firms that sell the non-standardized variety in the domestic market, the share of domestic firms that sell the standardized variety as well as the share of foreign firms that sell the non-standardized variety and the share of foreign firms that sell the standardized variety :

$$\begin{aligned} P_k =& M_k^{\frac{1}{1-\sigma_k}} \Big(\left(1 - \Delta^z \Delta^x\right) \left(p(\tilde{\varphi}_{iik})\right)^{1-\sigma_k} + \Delta^x \Delta^z \left(p(\tilde{\varphi}^h_{ijk})\right)^{1-\sigma_k} \\ &+ \Delta^x \left(\left(1 - \Delta^z\right) \left(p(\tilde{\varphi}_{ijk})\right)^{1-\sigma_k} + \Delta^z \left(p(\tilde{\varphi}^h_{ijk})\right)^{1-\sigma_k} \right) \Big)^{\frac{1}{1-\sigma_k}} \end{aligned} \tag{61}$$

The average prices are defined by the average productivities. Substituting the average producitivities back into the overall expression for the price index, we can solve for the price index and express the number of firms entering industry k as:

$$M_k = \left(\frac{\xi - (\sigma_k - 1)}{\xi} \frac{X_k}{\sigma_k f_{iik}} \right) \left(\vartheta_k(z)\right)^{-1} \tag{62}$$

where we combine the terms that depend on the standard into $\vartheta_k(z)$:

$$\vartheta_k(z) = \left(1 + \left(\Delta^x \Delta^z\right)^{1 - \frac{\sigma_k - 1}{\xi}} s\left(z_{jk}\right)\right) + \left(\Delta^x\right)^{1 - \frac{\sigma_k - 1}{\xi}} \tau_{ijk}^{1-\sigma_k} \left(1 + \left(\Delta^z\right)^{1 - \frac{\sigma_k - 1}{\xi}} s\left(z_{jk}\right)\right) \tag{63}$$

Variety reducing effect of introducing a harmonized standard

Equation 62 shows how the introducing of a harmonized standard affects the number of varieties within sector k. We compare this number of firms to an equilibrium with the same parameters but without standards. In this case $\vartheta_k(z) = 1$ and we can see from equation 62 that the number of firms in this equilibrium would be larger than in the case with harmonized product standards. The reason for this effect is that the introduction of the standard increases demand for high-valued standardized varieties, which reduces

demand for the non-standardized varieties and thereby reduces the overall number of firms producing in this sector.

Sectoral price index

Combining equations 60 and 62, we can express the cut-off for the domestic market as

$$(\bar{\varphi_{iik}})^{\xi} = \frac{f_{iik}}{f^e}\left[\left(\frac{(\sigma_k-1)}{\xi-(\sigma_k-1)}\right)(\vartheta_k(z))\right] \tag{64}$$

and together with the domestic cut-off condition in equation 52, we obtain the sectoral price index:

$$P_k = \left(\frac{\sigma_k}{\sigma_k-1}\right)^{\left(\frac{\sigma_k-1}{\sigma_k-\gamma}\right)}\left(\frac{\sigma_k f_{iik}}{P^{\gamma-1}L}\right)^{\frac{1}{\sigma_k-\gamma}}\left[\frac{f_{iik}}{f^e}\left(\frac{(\sigma_k-1)}{\xi-(\sigma_k-1)}\right)(\vartheta_k(z))\right]^{-\frac{1}{\xi}\left(\frac{\sigma_k-1}{\sigma_k-\gamma}\right)} \tag{65}$$

Demand effect of introducing a harmonized standard

The within-sector demand in industry k depends on the relative price between the sectoral price index and the aggregate price index as well as on the overall demand, i.e. $(C_k = (P_k/P)^{-\gamma}C)$. Equation 65 shows that the introduction of the standard reduces the price index $((\vartheta_k(z)) > 1)$ and thereby increases demand for the sector that introduces the standard. One can show that in a one sector model this positive demand outweighs the negative effect from the reduction in the number of varities and consumers are always better off with standards. In a multi-sector model, consumer welfare depends also on the cross-sectoral reallocation. The next paragraphs derive the implications for the aggregate price index, which is in our model a sufficient statistic for consumer welfare.

Consumer welfare measured by the overall price index

In equilibrium, the potential entrant is indifferent between entering any sector. Equation 57 implies that the number of firms in sector $k = 1$ divided by the probability of successful entry into sector 1 has to equal the number of firms in sector $k = 2$ divided by the probability of successful entry into sector 2, i.e. $M_1/(1-G(\bar{\varphi}_{ii1})) = M_2/(1-G(\bar{\varphi}_{ii2}))$. Substituting the expression for the sectoral domestic cutoff in equation 64 into the respective entry probabilities, we can express the ratio of firms in sector 1 relative to sector 2 as:

$$\frac{M_1}{M_2} = \frac{\frac{f_{ii1}}{f^e}\left(\frac{(\sigma_2-1)}{\xi-(\sigma_2-1)}\right)(\vartheta_2(z))}{\frac{f_{ii2}}{f^e}\left(\frac{(\sigma_1-1)}{\xi-(\sigma_1-1)}\right)(\vartheta_1(z))} \tag{66}$$

We assume that sector 2 has a higher elasticity of substitution than sector 1 and that there are no standards in sector 2, i.e. $\Delta_2 = 0$. These assumptions are in line with our empirical evidence in sector 7 and help to illustrate the effect of a harmonized standard on consumer

welfare. These assumptions imply that the ratio of the number of firms simplifies to:

$$\frac{M_1}{M_2} = \left(\frac{(\sigma_2 - 1)(\xi - (\sigma_1 - 1))}{(\xi - (\sigma_2 - 1))(\sigma_1 - 1)} \right) (\vartheta_1(z))^{-1} \tag{67}$$

Note from the cut-off conditions in equation 52, we can express the same ratio of the number of firms as follows:

$$\frac{M_1}{M_2} = \frac{\left(\frac{\sigma_1 f_{ii1}}{A_1}\right)^{\frac{-\xi}{\sigma_1 - 1}} \left(\frac{\sigma_1}{\sigma_1 - 1}\right)^{-\xi}}{\left(\frac{\sigma_2 f_{ii2}}{A_2}\right)^{\frac{-\xi}{\sigma_2 - 1}} \left(\frac{\sigma_2}{\sigma_2 - 1}\right)^{-\xi}} \tag{68}$$

where $A_k = P_k^{\sigma_1} X_k$ and $X_k = (P_k/P)^{1-\gamma}$. We can replace the A's and the prices P_1 and P_2 with the terms in equation 65 and set the two equations for the ratio of the number of firms per sector equal to each other. This allows to solve for the overall price index, which measures the consumer welfare:

$$P = L^{\frac{1}{1-\gamma}} \frac{\left[\frac{\sigma_1}{\sigma_1 - 1} (\sigma_1 f_{ii1})^{\frac{1}{\sigma_1 - 1}} \left(\frac{f_{ii1}}{f^e} \frac{(\sigma_1 - 1)}{\xi - (\sigma_1 - 1)} \vartheta_1(z) \right)^{\frac{-1}{\xi}} \right]^{\frac{(\sigma_1 - 1)(\sigma_2 - \gamma)}{(\sigma_2 - \sigma_1)(\gamma - 1)}}}{\left[\frac{\sigma_2}{\sigma_2 - 1} (\sigma_2 f_{ii2})^{\frac{1}{\sigma_2 - 1}} \left(\frac{f_{ii2}}{f^e} \frac{(\sigma_2 - 1)}{\xi - (\sigma_2 - 1)} \right)^{\frac{-1}{\xi}} \right]^{\frac{(\sigma_2 - 1)(\sigma_1 - \gamma)}{(\sigma_2 - \sigma_1)(\gamma - 1)}}} \tag{69}$$

When does the standard in industry 1 reduce welfare?

To assess under which conditions a standard can lead to lower consumer welfare, we follow Melitz and Redding (2015) and compare the consumer utility in the absence of standards to the consumer utility after the introduction of a harmonized standard for an identical set of parameter values. These parameters are the demand elasticities, fixed costs, entry costs, the shape parameters of the Pareto distribution, trade costs and labour endowment. Note that in the equilibrium without the standard, the overall price index equals equation 69 under the condition $\vartheta_1(z) = 1$. This implies that the introduction of a standard lowers consumer welfare or, equivalently, increases the overall price index when the following condition for the sectoral demand elasticities is satisfied:

$$\frac{(\sigma_1 - 1)(\sigma_2 - \gamma)}{(\sigma_2 - \sigma_1)(\gamma - 1)} < 0. \tag{70}$$

Given that $\sigma_2 > \sigma_1 > 1$ and $\sigma_2 > \gamma$, this condition implies that if the cross-industry elasticity is smaller than 1, then the release of a harmonized voluntary standard reduces welfare relative to a scenario without product standards.

C Appendix: ICS

Table 13: International classification of standards (ICS)

ICS class	Description
1	Generalities. Terminology. Standardization. Documentation.
3	Services. Company organization, management and quality. Administration. Transport. Sociology.
7	Mathematics. Natural sciences.
11	Health care technology.
13	Environment. Health protection. Safety.
17	Metrology and measurement. Physical phenomena.
19	Testing.
21	Mechanical systems and components for general use.
23	Fluid systems and components for general use.
25	Manufacturing engineering.
27	Energy and heat transfer engineering.
29	Electrical engineering.
31	Electronics.
33	Telecommunications. Audio and video engineering.
35	Information technology. Office machines.
37	Image technology.
39	Precision mechanics. Jewelry.
43	Road vehicles engineering.
45	Railway engineering.
47	Shipbuilding and marine structures.
49	Aircraft and space vehicle engineering.
53	Materials handling equipment.
55	Packaging and distribution of goods.
59	Textile and leather technology.
61	Clothing industry.
65	Agriculture.
67	Food technology.
71	Chemical technology.
73	Mining and minerals.
75	Petroleum and related technologies.
77	Metallurgy.
79	Wood technology.
81	Glass and ceramics industries.
83	Rubber and plastic industries.
85	Paper technology.
87	Paint and colour industries.
91	Construction materials and building.
93	Civil engineering.
95	Military engineering.
97	Domestic and commercial equipment. Entertainment. Sports.
99	(No title)

Source: ISO

D Appendix: Database construction

The original dataset comprises individual standards for which the date of release, the ICS class, the nationality of the standard-setting organization (SSO) as well as the duplicate versions in other SSOs are known ("links" to other standards). We denote these duplicates as "equivalences". The nationality of a SSO can either be a country ("national") or a European or international SSO ("international").

Linking all equivalent standards to one another

The original Perinorm dataset (which is part of the Searle Center Database on Technology Standards, Industry Consortia and Innovation) explicitly comprises a column where standard equivalences are listed; these essentially represent accreditations of a previously released standard by another SSO or the simultaneous release of a standard by more than one SSO. However, due to misreporting or chronological reporting, a single standard observation does not necessarily reveal all equivalences. In the case of chronological reporting, only equivalences known at the time of the release are listed and subsequent equivalences are only reported for newly released standards. For these reasons, one may for example encounter the following situation:

Table 14: Example of incomplete equivalences

Standard ID	Release date	Nationality of SSO	Equivalence
A	01/01/2000	FR	B
B	05/06/2005	DE	A, C
C	31/07/2012	FR	
D	04/08/2008	AT	B

All four standards, A, B, C and D, are equivalent, but this is not obvious when examining standards individually due to the incompleteness of the equivalence listings (which is most likely due to the fact that they were recorded in chronological order, i.e. when standard B was released, standard D did not yet exist, which is why it is not explicitly listed under its equivalences). For the purpose of identifying the originating country, we need to have the full information on these equivalences to determine which of the standards A, B, C or D was first released (standard A in the above example), and thus represents the original standard. All other standards, B, C and D, are then classified as accreditations of standard A.[43]

We use graph theory to identify all standards that belong to one group by assigning them the same group identifier.[44] In particular, we use the following breadth-first search algorithm (which we specifically adapt to the structure of the dataset) to connect all standards by exploring their equivalences:

[43]The accreditation of standard A due to the release of standard C is irrelevant information for our research question, as it concerns a within-country accreditation; we will thus drop the observation on standard C in the final dataset.

[44]We particularly thank François Farago for helping us with this procedure.

1. Initialize the group identifier, equal to a standard's row number in the dataset, for each standard.
2. Starting with $n = 1$, store the group identifier of standard n in the database (i.e. A).
3. Add the group identifiers of the equivalent standards, i.e. B, to the vector of stored group identifiers.
4. Note the smallest element of the vector of stored group identifiers.
5. Modify the group identifiers of standard n and its equivalent standards by assigning them the value identified in step 4 (i.e. A and B will have the same group identifier).
6. Delete the stored group identifiers.
7. Go on to the next standard $n + 1$ and repeat from step 2 onwards.

In order to minimize the computing power needed to run the algorithm, we use a simple hash function to build a dictionary of all standards whose IDs, which are strings, are mapped one-to-one to numeric values.

Identifying "originating country" and "accrediting country"

Once all equivalent standards have been grouped together, we identify the "originating country" by the nationality of the SSO who first released the standard. The nationalities of SSOs who released equivalent standards at a later date are used to classify the "accrediting countries". As such, a standard should have one originating country and one or several accrediting countries.

However, it is also possible that two or more SSOs release a standard at the same date.[45] International SSOs also constitute a "country" (country code "IX" in Figure 4). If two countries each released a standard at the same time, the respective standard is counted both as an original standard as well as an accreditation. However, if an international SSO and a national SSO release a standard at the same time, we consider that this standard originated in the international SSO (as it is very likely that the national SSO is a member organization of the international SSO and simply accredits standards of the international SSO at the same date as the latter one releases the standard). If two national SSOs are releasing a standard at the same time, both nationalities are registered as originating and accrediting countries.

Obtaining the relevant sub-sample

We eliminate the following standards to obtain the relevant subsample of all standard harmonizations:

[45] This situation arises most obviously when the date of the release is exactly the same. However, for some standards, only the year of the release is known, and in this case, two standards with the same release year will also be considered to have been released at the same date despite the fact that we cannot rule out the possibility that they were released at different dates over the course of the same year.

1. Standards that exist by themselves and are not linked to any other standard, meaning there is no other equivalent standard in the database.
2. Standards that constitute pure within-country accreditations or accreditations of a foreign standard after it was already accredited by another SSO of the same nationality.
3. Original national standards that were subsequently only released by SSOs of the same nationality.

Table 15: Procedure to define subset of data

Initial number of standards	1372038
Standards that are not linked to other standards (step 1)	577180
Duplicate accreditations within one country (step 2)	225837
Remaining national standards (step 3)	201647
Remaining standards in database	548123
of which: original bilateral standards	2726
of which: accreditations of bilateral standards	24021
of which: by national SSOs	21747
of which: by international SSOs	2274
of which: original international standards	76129
of which: accreditations of international standards	445247

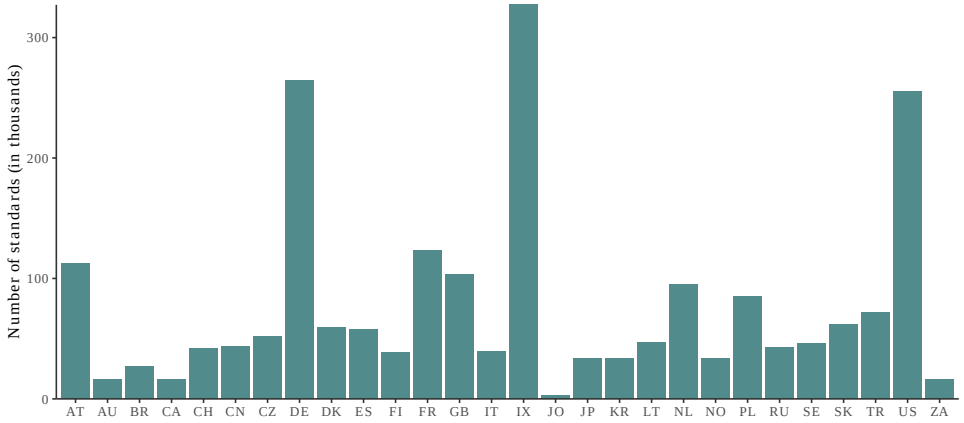
Notes: The table displays the number of standard releases over the years 1995–2014, broken down by national and harmonized standards. The latter are also broken down by their means of accreditation. Bilateral standards are those harmonized standards that are released/accredited by national SSOs only while international standards are those that originate in international SSOs.

Figure 4 (a) displays the country distribution of the raw data. We note the strong representation of Austrian, German and US standards. Besides the non-excludable possibility that these countries are very active in the standard-setting process, this could be due to more comprehensive reporting for the SSOs of these countries as well as the duplicate release of the same standard within one country due to institutional practices. Figure 4 (b) displays the country distribution of the relevant subset for our analysis: the dominance of Austrian, German and US standards vanishes in the subsample.

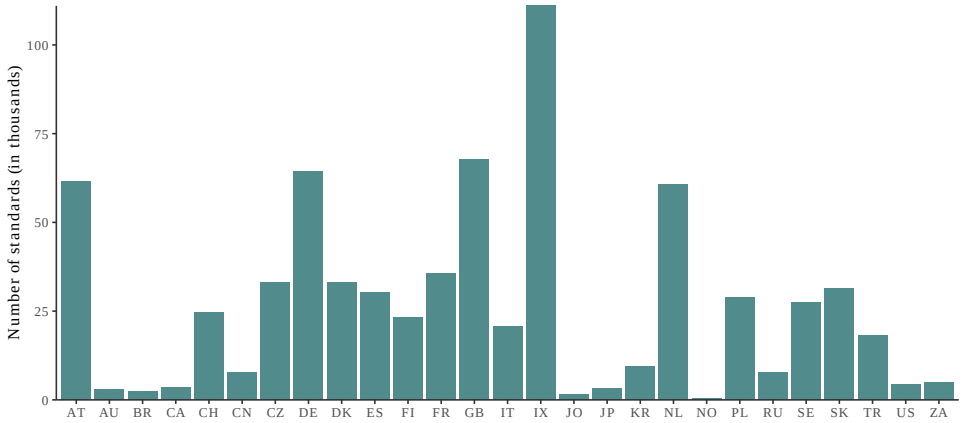
The data presented in Figure 4 show that a large number of standards documents are released by international SSOs. A large amount of this international dimension of standard harmonization is due to the European integration process and the accompanying dominance of European SSOs among international SSOs. Table 16 lists the largest international SSOs (in terms of original standards). As their names reveal, many of these SSOs are European ones. However, it should be noted that many of these SSOs were founded as part of the European integration process, but also produce international standards and are comprised of non-European members (one such example is ETSI).

Figure 4: Country distribution before and after cleaning

(a) Raw data



(b) Relevant subset



Notes: The figure displays the number of standards, broken down by the nationality of the respective SSO. The data are summed over the years 1995–2014 and all ICS classes. Panel (a) displays the distribution based on the original dataset, while panel (b) displays the distribution after the data have been cleaned according to the criteria described in this appendix.

Table 16: Top ten international SSOs (release of original standards)

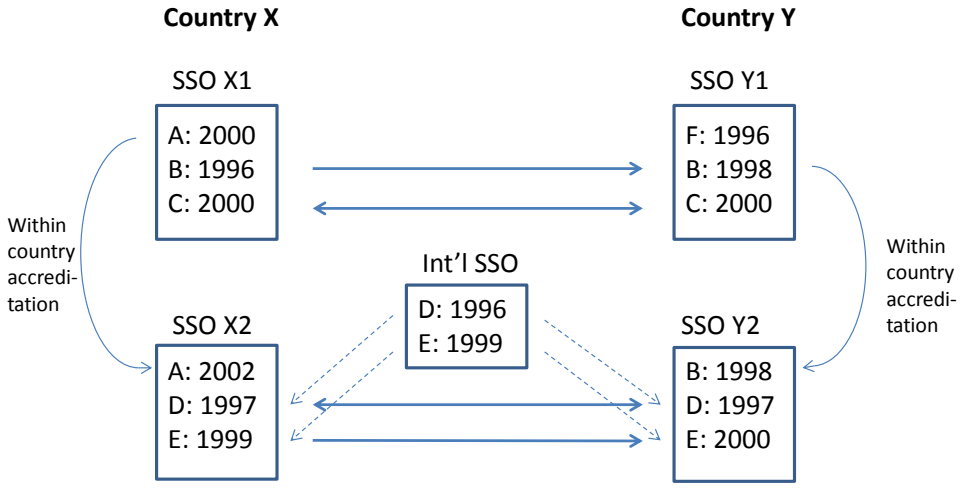
SSO	Number	in %
CEN – European Committee for Standardization	25449	33.4
ISO – International Organization for Standardization	22259	29.2
IEC – International Electrotechnical Commission	14083	18.5
CENELEC – European Comm. for Electrotechnical Standardization	6894	9.1
ETSI – European Telecommunications Standards Institute	4930	6.5
ASD – AeroSpace and Defence Industries Association of Europe	1594	2.1
ITU – International Telecommunication Union	291	0.4
ECMA – European Asso. f. Standardizing Info. and Comm. Systems	120	0.2
IDF – International Dairy Federation	83	0.1
CCSDS – Consultative Committee for Space Data Systems	81	0.1
Other	345	0.5
Total	76129	100

Notes: The table displays the number of original standards of international SSOs, broken down by SSO. A standard can be released by more than one SSO per year and can thus be counted several times. The data are summed over the years 1995–2014 and all ICS classes.

Construction of identifiers for harmonization events

A standard document can either be a national standard, meaning that it was released by a national SSO and never accredited by a SSO of another nationality (such as standards A and F in Figure 5), or a harmonized standard, meaning that at least two versions of the same unique standard have been released by at least two SSOs of different nationalities (such as standards B, C, D and E in Figure 5).

Figure 5: Terminology



We consider a standard harmonization event to take place whenever the importer of a product accredits a standard that was already released or is being released in the same year by the exporter. As demonstrated in Figure 5, this can be the case when country Y accredits the standard B in 1998 that was originally released by country X in 1996. A

harmonization event also takes place whenever two countries accredit a standard that was originally released by an international SSO. In the example in Figure 5, this is the case for standards D and E.

Table 17: Coding of harmonization events

Exporter	Importer	Year	Harm. events	Dummy
X	Y	1996	–	0
X	Y	1997	D	1
X	Y	1998	B	1
X	Y	1999	–	0
X	Y	2000	C + E	1
Y	X	1996	–	0
Y	X	1997	D	1
Y	X	1998	–	0
Y	X	1999	–	0
Y	X	2000	C	1

In Table 17, we show how we code the harmonization events. The year of the harmonization is the point in time when the importing country accredits the standard, i.e. 1998 for the case of standard B in the example of Figure 5. When the two countries accredit the same standard in the same year, as is the case of standard C in the example, we record it as a harmonization event both when considering exports from X to Y in the year 2000 as well as exports from Y to X in the year 2000.

E Concordance table

One of the key identification issues in quantifying the impact of standard harmonization on international trade is linking the standard documents to their corresponding products. The International Standard Classification (ICS) system groups standards according to economic sector, the underlying technology or activity, such as environmental protection, safety assurance or protection of public health. On the other hand, products in international trade data are categorized according to the Harmonized System (HS) established by the World Customs Organization (WCO).

The HS nomenclature follows trade policy concerns such as tariffs and not necessarily the production characteristics of the product. The non-existence of a concordance is one of the main reasons why previous papers in the literature cover only certain industries; see Moenius (2006), Reyes (2011) or Fontagné et al. (2015). This paper tackles the concordance issue in two ways. First, we use a newly developed concordance table from the WTO with the drawback that some links between key standard categories and products are missing. As a second step, we develop an alternative all-industry concordance table using keyword-matching techniques. We briefly describe both approaches below.

Concordance table based on WTO's TBT IMS database

The WTO concordance table is based on the Technical Barriers to Trade Information Management System (TBT IMS) database of the WTO. The TBT IMS is a publicly available database of transparency information provided by WTO members in relation to technical regulations, conformity assessment procedures and standards.[46] A typical notification of a member country consists of an explanation of why it imposes a technical barrier to trade, which partner country is affected, the ICS classification of the TBT and, in some instances, it also includes the 4-digit HS code (in some instances the 2-digit or the 6-digit code) for the products on which the measure is applied.

All the notified relationships between HS and ICS classes for the period 2000 to 2016 amount to 3775 notifications, of which several mention one or more HS and ICS classes. There are a total of 2391 links between HS and ICS, and these make up 0.5% of all possible links. Of the identified relationships, 32% cover multiple relationships and lead to a many-to-many concordance. One of the drawbacks of this concordance table is potential underreporting because there will only be links for those HS-ICS relationships for which there was actually a notification at the WTO. In addition, there might be biased reporting, as WTO members have different incentives to report to the WTO depending on the importance of the export and import flows pertaining to a particular product.

Concordance table based on keyword matching

We use a rich set of fixed effects to tackle the issues mentioned above. However, identification concerns of neglecting key standard-product links remain. To mitigate this concern, we

[46] The table is available at https://i-tip.wto.org/goods/Forms/Methodology.aspx.

construct another concordance table based on keyword-matching techniques described in a companion paper (Han et al., 2019). The main idea is to use keywords describing individual standards (obtained from the German Institute for Standardization DIN, Deutsches Institut für Normung e.V.) and match them with keywords extracted from the descriptions of the product categories in the Harmonized System.

The first step reduces the set of keywords via a stemming algorithm. We consider only the present tense of a verb and the singular of a noun. After having unified each word, a keyword algorithm extracts all the keywords from the HS and ICS classification and attaches an importance weight to each of them. The importance weight is determined by the inverse-document frequency (how distinctive the word is in the overall classification scheme). We then calculate the combined weight for each HS 4-digit and ICS 5-digit category and normalize this combined weight by the number of keywords in each classification scheme. We then choose a threshold below which we consider the respective HS-ICS links as irrelevant. This threshold value is chosen to keep as many of the links that appear in the WTO concordance table as possible while reducing the total number of links.

We obtain a concordance table with 994 links between the ICS 5-digit and HS 4-digit categories. Given that the quality of the match is not as good as the one by the WTO (which is based on human knowledge), we use this table as a robustness check. The advantage of the keyword-matching algorithm is that it is unbiased and comprehensive.

F Appendix: Additional empirical results

Multiple harmonization events

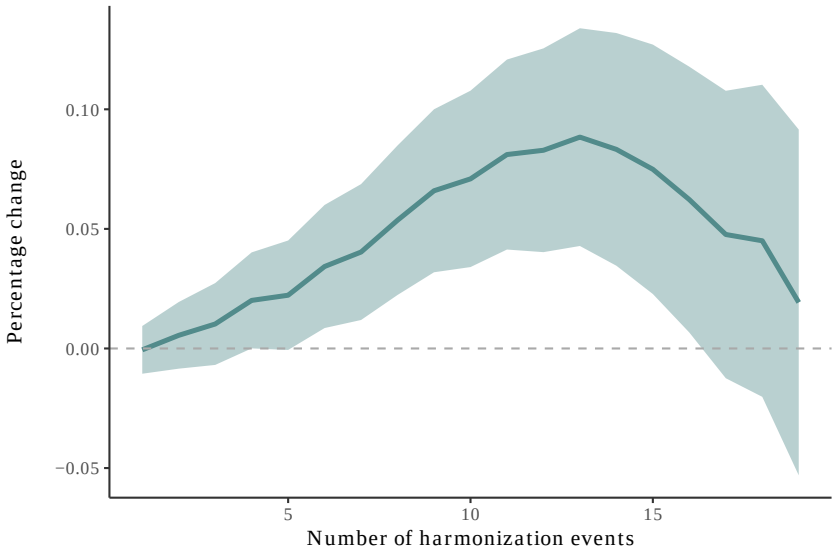
In contrast to most difference-in-difference set-ups, each exporter-importer-product triplet can be subject to multiple treatments over the time period in question. The baseline specification estimates the marginal effect of a standard harmonization event on trade flows relative to non-harmonized flows, assuming that this effect is constant. However, the positive effects of standard harmonization might take time to materialize. For this reason, we consider a non-parametric specification, where we allow the marginal effect to depend on the number of times a product experienced a harmonization event. The corresponding regression specification looks as follows, where the subscript n indexes the n-th harmonization:

$$\log(X_{ijkt}) = \sum_{n}^{20} \beta_n h_{n,ijkt} + f_{ikt} + f_{jkt} + f_{ijt} + f_{ijk} + \varepsilon_{ijkt} \tag{71}$$

The dummy $h_{n,ijkt}$ equals 1 if a product was harmonized n times and zero otherwise. The variable measures the difference in the average trade flow of a product that was harmonized n times compared to a product that was never harmonized.

Figure 6 plots the coefficients β_n from the above-specified regression set-up together with the 95% confidence interval. Panel (a) shows that the marginal effect of standard harmonization on trade flows is more or less constant in the number of harmonization events (up to 12-13 events), with each subsequent harmonization contributing a similar positive amount to overall trade flows. Afterwards the additional effect declines slightly, but the overall effect remains positive.

Figure 6: Cumulative effect of multiple harmonization events



Notes: The figure displays the coefficient estimates of a regression of the respective dependent variable (designated in figure subtitles) on dummies for each subsequent harmonization within an exporter-importer-product triplet (regression specification 71). Shaded regions represent 95% confidence intervals.

Results using the keyword-matching table

All results in the main part of the paper are obtained using the concordance table extracted from the WTO's TBT IMS database. As a further robustness check, we run the regression on the dataset using the concordance table obtained via keyword-matching techniques. Results for the baseline regression specification 18 are displayed in Table 18 and show similar, though slightly smaller coefficients.

Table 18: Regression results / Concordance based on keyword matching

Dependent variable:	log(exports)		
	(1)	(2)	(3)
	Total	Total	Total
Harm.	0.09584***	0.01702***	0.00369*
	[0.000]	[0.000]	[0.061]
Observations	4303956	4257616	4257598
R^2	0.21	0.88	0.88
Adjusted R^2	0.21	0.85	0.85
Exporter-time FE	yes	no	no
Importer-time FE	yes	no	no
Exporter-importer FE	yes	no	no
Exporter-product-time FE	no	yes	yes
Importer-product-time FE	no	yes	yes
Exporter-importer-time FE	no	yes	yes
Exporter-importer-product FE	no	no	yes

Notes: Regression of the respective dependent variable (designated in column headers) on harmonization indicator. Fixed effects are included as described in the regression specification 18. Standard errors are clustered at the exporter-product-level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

PPML regressions

As a further robustness check, we make use of recent advances in the estimation of PPML as advocated by Silva and Tenreyro (2006) and made feasible by the use of high-dimensional fixed effects thanks to Larch et al. (2019). In particular, we regress total trade flows in levels (not in logs, thus including zero trade flows) on our variable of interest as in the baseline specification. Results are displayed in Table 19. Estimating the model with the PPML estimator produces estimates of standard harmonization very similar to our baseline specification (see columns (1) to (3) of Table 19).

Table 19: Regression results / PPML

Dependent variable:	log(exports)		
	(1)	(2)	(3)
	Total	Total	Total
Harm.	0.00957***	0.01357***	0.00446***
	[0.00028]	[0.00066]	[0.00105]
Observations	10330834	8638961	8638552
Exporter-time FE	yes	no	no
Importer-time FE	yes	no	no
Exporter-importer FE	yes	no	no
Exporter-product-time FE	no	yes	yes
Importer-product-time FE	no	yes	yes
Exporter-importer-time FE	no	yes	yes
Exporter-importer-product FE	no	no	yes

Notes: Regression of total trade flows on harmonization indicator. The type of estimation is specified in the panel header. Fixed effects are included as described in the regression table. Robust standard errors are included and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.

Multi-product firms

To provide one additional robustness check, we tighten our identification strategy and focus on differences in product-level export sales within the firm. More precisely, we focus on multi-product firms and compare their export sales of a product where standard harmonization took place with export sales of products where there was no standard harmonization. This comparison is within the firm and restricts potential confounding factors due to a comparison of multi-product firms and single product firms as in our baseline specification.

The results of these regressions are shown in Table 20. Column (1) shows the estimate of the difference in export sales of a product with standard harmonization and to a product without standard harmonization. The estimated coefficient of 0.0096 is larger than our firm-level baseline estimate in Table 8 of the paper. In column (2) to (5) we repeat this exercise but split the sample into difference size bins. In columns (2)–(4) which correspond to the first, second and third quartiles, the results show no evidence of a significant difference between export sales of a product with standard harmonization and a product without standard harmonization. However, in column (5) where we restrict the sample to the largest 25% of firms, we find that a firm's export sales of a product where standards are harmonized are significantly higher compared to the firm's export sales of a product that did not experience a standard harmonization event. These results provide further evidence on the main results in the paper, namely that standard harmonization increases export sales, but only for large firms.

Table 20: Regression results for multi-product firms / Firm-size distribution

Dependent variable:	log(export sales)				
	(1) All firms	(2) 1st quartile	(3) 2nd quartile	(4) 3rd quartile	(5) 4th quartile
Harm.	0.00955***	0.00491	-0.00152	0.00216	0.01895***
	[0.00230]	[0.00374]	[0.00425]	[0.00420]	[0.00336]
Observations	6363164	1560930	1536202	1566729	1536926
R^2	0.85	0.84	0.85	0.86	0.85
Adjusted R^2	0.80	0.74	0.78	0.81	0.81
Firm-product-time FE	yes	yes	yes	yes	yes
Firm-destination-product FE	yes	yes	yes	yes	yes

Notes: Regression of the log of export sales on harmonization indicator for different firm-size bins. Columns (1) contains the first quartile of firms with the smallest size. Column (2) contains firm in the second and column (3) in the third size-quartile. Column (4) contains the fourth quartile with the largest 25% of exporting firms. Fixed effects (FE) are included as described in the regression specification 23. Standard errors are clustered at the destination-HS4 product level and reported in brackets. ***, ** and * indicate respectively 1%, 5% and 10% significance levels.