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An empirical investigation of information systems interoperability business value in European firms

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ABSTRACT

It is widely believed that the establishment of interoperability of the information systems (IS) of a firm with those of its collaborators (e.g. customers, suppliers, and business partners) can generate significant business value. However, this has been empirically investigated only to a very limited extent. This paper contributes to filling this research gap by presenting an empirical study of the effect of adopting the three main types of IS interoperability standards (industry-specific, proprietary and XML-based ones) on the four important perspectives/dimensions of business performance proposed by the balanced scorecard approach (financial, customers, internal business processes, learning and innovation). Our study is based on a large dataset from 14,065 European firms (from 25 countries and 10 sectors) collected through the e-Business Watch Survey of the European Commission. It is concluded that all three examined types of IS interoperability standards increase considerably the positive impact of firm's information and communication technologies (ICT) infrastructure on the above four perspectives/dimensions of business performance; however, their effects differ significantly. The adoption of industry-specific interoperability standards has the highest positive effects, while XML-based and proprietary standards have similar lower positive effects. Furthermore, these effects of the industry-specific IS interoperability standards are quite strong, as they are of similar magnitude with the corresponding effects of the degree of development of firm's intra-organizational/internal IS, and of higher magnitude than the corresponding effects of the degree of development of firm's e-sales IS. These conclusions provide valuable empirical evidence of the multidimensional business value generated by IS interoperability, its big magnitude and its strong dependence on the type of IS interoperability standards adopted.

1. Introduction

Interoperability, defined by IEEE as the 'ability of two or more systems or components to exchange information and to use the information that has been exchanged' [1], has been regarded for long time as a significant source of business value. It is widely believed that the establishment of interoperability of the information systems (ISs) of a firm with the ones of other cooperating firms (e.g. customers, suppliers, and business partners) can generate significant business value. IS interoperability is regarded in the 'Digital Agenda for Europe' [2] of the European Commission as a fundamental pre-condition for the development of an advanced digital economy and society in the European Union, and also as a factor of critical importance for the success of 'Europe 2020' strategy for smart, sustainable and inclusive growth [3]. In the same direction the final report of a high-level informal study group (ISG) launched by the European Commission (EC) to investigate the value proposition of enterprise interoperability [4] concludes that IS interoperability has a great potential to increase the performance of firms' business processes, to support deeper cooperation among firms and to stimulate new value creation through innovation. In the same report it is emphasized that today, due to the increasing globalization of the economy, firms have to be active, compete and cooperate with other firms in many countries, and participate in international networks, and this increases further the need for and the value of having interoperable IS.

However, the above high expectations concerning the business value that IS interoperability can create have not been sufficiently tested empirically. As explained in more detail in the following Section 2 only a very small number of empirical studies have been conducted on the business value of IS interoperability. The 'Enterprise Interoperability Research Roadmap' [5] developed under the auspices of the EC concludes that 'Large question marks remain as regards the "value" and "impact" of the myriad of initiatives undertaken within the research lab, promoted by technology providers, or organized around groupings of companies', and calls for systematic research on this question. This gap is

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also strongly emphasized in the abovementioned EC report on the value proposition of enterprise interoperability [4], which remarks that there is a lack of study and evidence of the value and impact of IS interoperability, and this has negative impact on its adoption by firms, and especially by SMEs; for this reason it recommends that it is necessary to put more emphasis and conduct more research on this critical issue. Therefore more empirical research is required concerning the business value that IS interoperability creates in order to understand better its main dimensions, its magnitude and the factors affecting it.

This paper contributes to filling this research gap. In particular, its main contributions are:

1. It adds to the quite limited empirical literature on the business value of IS interoperability by presenting an empirical study of the effect of semantic-level IS interoperability on business performance, which is based on a large dataset collected from 14,065 European firms (from 25 countries and 10 sectors) through the e-Business Watch Survey of the European Commission.
2. It examines this effect not only with respect to firm's financial performance, but also with respect to all the four main business performance perspectives/dimensions proposed by the well-established balanced scorecard approach (financial, customers, internal business processes, learning and innovation) [6–9], which has been repeatedly used in empirical IS studies in the past [10–13], based on the arguments and recommendations of [14].
3. It examines and compares the effects on business performance of adopting the three main types of semantic layer IS interoperability standards: industry-specific standards, proprietary standards and XML-based standards [15–17].
4. It also examines the magnitudes of these effects in a 'pragmatic' manner, by comparing them with the corresponding effects of the 'classical' determinants of the business value a firm derives from information and communication technologies (ICT): the degree of development of its intra-organizational (internal) and e-sales IS.

The industry-specific standards have been created mainly by industry associations or sectoral standardization bodies, in order to enable the electronic exchange of important business documents (e.g. quotations, orders, shipment notes, invoices, and payment notes) between firms of a specific industry, their suppliers, customers and business partners. As a typical example one may consider the health sector specific standards published and maintained by organizations like the Clinical Data Interchange Standards Consortium (CDISC) (see http://www.cdisc.org/). Such industry-specific standards usually are 'tailored' to meet the needs of the firms of the specific sector, so they have exactly the whole needed "depth and breadth": they include all the range of the required elements of the exchanged business documents (even the specific ones to the particular industry), and at the same time they do not carry additional elements that would serve other industries.

The proprietary standards are typically being created and maintained by large and strong firms which can act as channel masters, imposing such de-facto specifications to their customers, suppliers or business partners. Such interconnection standards are still very popular in several sectors, e.g. in the large, multinational supermarket chains for accepting electronic invoices from myriads of small and medium suppliers. As a typical example we can mention the TESCO electronic invoicing specifications (see Tesco Invoice Delivery Service, at http://tesco.gxs.co.uk). They usually have extensive depth and breadth, but include mainly the elements required by the strong creator firm.

The XML-based standards are typically cross-sectoral, more open and customizable specifications of business documents' interchange formats, based on the XML (eXtensible Markup Language), aiming to be used by firms of all sectors. Typical examples of XML-based standards are the Universal Business Language (UBL) specifications (providing a library of standard XML specifications for the most frequently used business documents, to be used in general procurement and transport contexts, see https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=ubl), or the eXtensible Business Reporting Language (XBRL) (supporting financial information exchange, see http://www.xbrl.org). They are broad enough to cover many important aspects of the documents that need to be exchanged among firms, but lack the needed depth for representing sector-specific characteristics and information elements, as they have been developed with a 'least common denominator' logic, i.e. they include mainly elements that are common across sectors. Due to the fast adoption of XML by the industry, such standards lately penetrate in practically every sector, and at the same time many associations and key industrial players are slowly porting their specifications to XML.

In order to reach a higher maturity in the interoperability domain, and create a sound scientific base of it, it is necessary not only to develop interoperability architectures, frameworks, methods and standards, but also to examine empirically their business value and impact on various important dimensions of business performance, at the level of the individual firm and the whole supply chain [18–20]; this is going to assist in making more informed decisions concerning the adoption of such interoperability architectures, frameworks, methods and standards, taking into account not only technical, but also business value factors as well. Our study contributes in this direction, by investigating empirically the impact at the firm level of the three main types of semantic-layer IS interoperability standards on four important dimensions of business performance, based on a large European dataset. We believe that the findings of this study are useful to the rapidly growing community of researchers, practitioners, and also consulting and ICT companies, working in the area of IS interoperability. Furthermore, they are useful to standardization bodies and also to government organizations of various layers responsible for the design and implementation of policies for the development of digital economy and society in their constituencies. Finally, our findings are useful to individual firms formulating their IS interoperability strategies.

Our paper is structured in six sections. In the following Section 2 a review of relevant literature is presented, while in Section 3 the research design and hypotheses are described. The data and method of our study are described in Section 4, while the results are presented and discussed in Section 5. Finally in Section 6 the conclusions are summarized and future research directions are proposed.

2. Literature review

Previous literature has identified and discussed various dimensions of the business value that IS interoperability generates. It is worth reviewing in more detail some representative studies in this area, which combine conclusions from several relevant publications. Choi and Whinston [21] argue that IS interoperability is fundamental in order to maximize the benefits from computing and networking technologies, and make full exploitation of their potential. In particular, it allows firms to communicate, exchange information, deliver products and services in real time, and this results in significant business benefits. It can improve efficiencies in managing multi-partner transactions, in which multiple transactions occur among numerous participants who are very

often dispersed geographically. In general it can significantly improve efficiency in product design, manufacturing and distribution, and at the same time increase customers' choices and satisfaction. At the same time IS interoperability is a key enabler of advanced and highly beneficial business practices, such as supply chain management, logistics management, knowledge management, online retailing and auction markets, since it can reduce their costs and make them easier to implement. The same paper also argues that the business value generated by interoperability is not limited to efficiency gains, as it can be a fundamental driver and enabler of important collaborative innovations; it enables the personalization of offerings and the composition at a low cost of new complex products/services by combining and bundling complementary products/services from many different suppliers who are active in traditionally separated markets. Grilo et al. [14] argue that firms today increasingly tend to be active in several countries, so they have to cooperate with more and geographically dispersed suppliers and customers; also, they have to change the way they produce and innovate, increase productivity and flexibility, achieve higher levels of integration of their internal value chain and of the external supply chains in which they participate, and to exploit better the information rich supplier and distribution chain. Establishing IS interoperability with trading partners is of critical importance for meeting the above requirements. The same paper identifies three main functions of IS interoperability which can generate significant business value: informational function (exchange of information of various levels of complexity), transactional function (electronic execution of the whole life-cycle of various types of transactions) and collaboration function (collaborative products/services design and development). Due to this multi-dimensional value generated by IS interoperability it is suggested that a balanced scorecard approach should be adopted for measuring it. The abovementioned report on the 'Enterprise Interoperability Research Roadmap' [5] sheds light on the significance of IS interoperability for the formation and operation of 'virtual organizations', defined as 'groupings of legally distinct or related enterprises coming together to exploit a particular product or service opportunity, collaborating closely whilst still remaining independent and potentially competing in other markets or even other products/services in the same market'. IS interoperability is of critical importance for the sharing of knowledge within a virtual organization and for making better decisions based not only on 'local' information (coming from one of the enterprises participating in the virtual organization), but also on 'global' information (coming from all the participating enterprises), which can both increase significantly its competitiveness and profitability. For these reasons it is finally concluded that one of the 'grand challenges' for IS interoperability research is to gain deeper understanding of the above capabilities and to make better exploitation of them.

The value proposition of IS interoperability is elaborated in more detail in the abovementioned report on 'Unleashing the Potential of the European Knowledge Economy–Value Proposition for Enterprise Interoperability' [4]. It concludes that IS interoperability has the potential to improve efficiency dramatically, which has been the main focus in the past, but additionally can also drive the collaborative development of significant value innovation by 'value networks', defined according to Allee [22] as 'webs of relationships that generate tangible and intangible value through complex dynamic exchanges between two or more individuals, groups, or organizations'. In this direction it defines the new value proposition of IS interoperability as "Value innovation derived from new forms of open collaboration and channels targeting new, global and highly customized niches, and grounded in interoperable complex ecosystems, connecting end-users, producers, suppliers, software vendors, telecommunication companies, public bodies and citizens; empowering employees; and sustaining stronger economic growth". The same report proposes an 'Enterprise Interoperability Value Framework' (EIVP), which identifies five types of interaction among firms that can be supported and enhanced by the interoperability of their IS:

1. Communication – exchange of information.
2. Coordination – alignment of activities for mutual benefit, avoiding gaps and overlaps, in order to achieve efficiency gains.
3. Cooperation – obtaining mutual benefits by sharing or partitioning work, or by establishing supply chain visibility, where manufacturers and distributors allow each other's visibility of stocks, sales and production plans in order to optimize value chain stocks.
4. Collaboration – an engagement to work together in order to achieve results and innovative solutions that the participants would be unable to accomplish alone.
5. New sales channels – "selling less of more products", which, according to Anderson [23], means producing a wider range of products and gaining greater access to small niche markets for selling these products.

While the first of the above interaction types support mainly 'red ocean strategies' (in which firms compete for selling existing established products and services through lower prices or marginal innovations), the last ones support and facilitate 'blue ocean strategies' (in which firms aim to create new market spaces, or "blue oceans", making the competition irrelevant, by introducing radical innovations in the products, services and processes), using the terminology introduced by Kim and Mauborgne [24,25]. Also, according to this framework the scope of exploitation of IS interoperability can vary considerably, and this is a significant determinant of the magnitude of the business value generated. In particular, interoperability can be exploited for achieving internal information integration (i.e. for making interoperable the applications of different organizational units of the firm), or have a wider scope aiming at supporting specific dyadic business relationships, a hub-spokes structure, or even business networks; widening the scope of exploitation will result in more business value. The above EIVP framework has already been successfully used for analysing IS interoperability in the Architecture, Engineering and Construction (AEC) sector [26,27].

Recently, in their introductory paper [19] of a Special Issue on ' Sustainable interoperability: The future of Internet based industrial enterprises', Jardim-Goncalves et al. argue that IS interoperability is a key enabler for unlocking the full potential of organizations, processes and systems in both the public and private sector, enabling seamless cooperation among organizations in all stages of development and production of goods and services, reducing barriers to communication and fostering a new networked business culture. It is also emphasized that IS interoperability has a great potential for supporting substantially not only established and stable networks based on long term collaborations, but also less stable networks that continuously evolve adapting changes in the business environment, or even short-lived collaborative initiatives (e.g. having the form of a consortium) for the exploitation of business opportunities.

IS interoperability constitutes a valuable infrastructure, which facilitates and drives various advanced and highly beneficial business practices, making them less costly and more easy and quick to implement and beneficial. Such business practices are:

- Electronic data interchange (EDI) [13,28–30], which allows the electronic exchange of various types of structured business documents with customers, sales channels, suppliers, business

partners, etc. (e.g. quotations, orders, shipment notes, invoices, and payment notes), resulting in significant operational and strategic benefits.
- Collaborative planning, forecasting and replenishment (CPFR) [31–33], which is defined as the combination of data and the intelligence of multiple trading partners across the supply chain in order to improve planning and fulfilment of customer demand.
- Vendor-managed inventory (VMI) [34–36], defined as a new approach to inventory management, in which the supplier assumes the responsibility of tracking and replenishing firm's inventory; it can improve customers' service and at the same time reduce inventory cost.
- Open innovation [37–40], defined as the use of input (e.g. ideas, remarks, needs, knowledge, and market information) from outsiders (such as customers, suppliers and business partners) in firm's innovation process, in order to make it more productive and expand the markets for the innovative products; innovation design and implementation processes of firms recently tend to become more and more open, initially in the high-tech industries, and later in other industries as well. Such open innovation practices can be facilitated and enhanced by IS interoperability allowing the easy exchange of innovative products' design files (e.g. at various stages of theirdevelopment, or different alternative designs of them), and also remarks and suggestions on them, and relevant demand and production plans, with customers, suppliers and business partners.
- Participation in value networks, virtual organizations and digital business ecosystems [41–45], in which innovative products and services offering higher levels of value to customers are collaboratively conceived, designed, produced and delivered, and the distinction between provider and customer gradually disappears, as customers co-create with producers highly innovative products and services.
- Creation of new business models [46–49], which are defined as new value propositions and value production architectures in combination with appropriate models of revenue and profits generation.

It should be emphasized that the extent of exploiting the above capabilities finally determines the extent of value generation from IS interoperability.

However, the business value of IS interoperability has been only to a very limited extent investigated empirically using large datasets; only a very small number of empirical studies have been conducted on IS interoperability business value. Boh et al. [50] investigate empirically the effect of a single industry-specific standard (the RosettaNet, a standard aiming to facilitate B2B electronic transactions in high-tech industries, such as semiconductor manufacturing and telecommunications) extent of deployment and integration in business processes on the operational and strategic benefits that adopting firms obtain; it is based on dataset collected from 62 firms from China, Japan, Malaysia, Singapore and Taiwan. It concluded that integration and deployment of this standard have similar positive effects on the strategic benefits, while the former is the main determinant of the operational benefits. Mouzakitis et al. [51] investigate empirically the effect of five layers of interoperability (network, data, application, process and business) on the required effort for B2B IS integration; it is based on a dataset collected from 239 Greek firms which had successfully completed at least one B2B IS integration project. It was concluded that IS interoperability at the data, process and business levels is significantly associated negatively with integration effort.

Therefore, only a very small number of empirical studies have been conducted on the business value generated by IS interoperability, all based on small datasets collected from firms of a single country. Furthermore, these few empirical studies do not investigate the different aspects of business value generated by IS interoperability (i.e. its impacts on various aspects of firm's operation and performance), do not examine its effect on firm's innovation activity, and also do not examine and compare these effects for different types of standards. Also, the research frameworks employed do not allow 'pragmatic' assessments of the magnitude of the value generated by IS interoperability by comparing its impacts on various perspectives/dimensions of business performance with the ones of the 'classical' determinants of ICT-related business value at the firm level, such as the degree of development of firm's intra-organizational IS or e-sales IS.

3. Research design and hypotheses

The present study contributes to filling the above empirical research gaps concerning the highly important issue of IS interoperability business value, focusing on semantic layer interoperability, a very important and fundamental layer of interoperability (taking into account that the wide use of Internet by firms has led to high levels of IS interoperability among firms at the lower network layer). In particular, this study examines the effects of adopting the three main types of IS interoperability standards, the industry-specific, proprietary and XML-based standards, on the four perspectives/dimensions of business performance proposed by the well-established balanced scorecard approach [6–9] (financial, customers' value, internal business processes, learning and innovation), recognizing the multi-dimensional nature of the business value generated by IS interoperability according to previous relevant literature (see Section 2). Since the above four dimensions of firm's business performance are influenced to a large extent by many internal and external factors, in addition to ICT usage, we have focused on the impacts of firm's ICT infrastructure on these four business performance dimensions as our dependent variables (an approach adopted by many previous empirical studies in the area of IS, e.g. [52–54]), and examine the effects on them of adopting the above IS interoperability standards.

Our first research hypothesis concerns the effect of adopting IS interoperability standards on the impact of firm's ICT on the performance of its business processes. These standards allow the easy and low cost exchange of various types of data between the firm and its customers, suppliers and business partners, without the need of developing complex data conversion programmes or human interventions. The exchanged data can be both at the informational and the transactional mode (using the terminology introduced in the previous Section 2), and can concern quotations, orders, shipments, receipts, invoices, payments and returns, or even descriptions of products and services at various levels of detail [28,29]. Also, data can be exchanged that support and enhance coordination and collaboration, for instance data on stock levels, production plans, sales forecasts, or on common projects [32,36]. This electronic data interchange generates significant operational benefits, such as less paperwork resulting in reductions in administrative personnel, less errors, faster payments/improved cash-flow, avoidance of production stoppages resulting from lack of raw material, reduction of purchasing/sales cycles (ordering, delivery and invoice) and reduction of stock levels [28]. The above are expected to increase the impact of firm's ICT infrastructure on the performance of business processes. Therefore our first research hypothesis is:

H1. The adoption of IS interoperability standards increases the impact of ICT on firm's business processes performance.

The adoption of IS interoperability standards is also expected to increase the value offered by a firm to its customers. It allows the

easy and low cost electronic execution and completion of customers' transactions through the electronic exchange of quotations, orders, shipment notes, invoices and payment notes, which will reduce their transaction costs and at the same time will increase the speed of delivery to them of our products and services [13,21]. The free flow of data between a firm and its customers that IS interoperability enables contributes positively to the improvement of important customer service components, such as order cycle time, product availability, distribution information provision, distribution correctness and distribution flexibility [55]. At the same time it reduces the cost of the personalization of products and services offered to customers so that they serve their specialized needs and tastes, and the composition of complex products/services by bundling complementary products/services from many different suppliers [4,21]. In general IS interoperability supports a more intensive interaction between a firm and its customers, so that collaborative 'value co-creation' [28] can take place. For the above reasons we expect that firm's IS interoperability will increase the impact of its ICT infrastructure on the value offered to its customers. Therefore our second research hypothesis is:

H2. The adoption of IS interoperability standards increases the impact of ICT on the value offered to customers.

Furthermore, the establishment of IS interoperability with existing and potential customers, suppliers and business partners that these standards enable can be very useful for the collaborative design and implementation of innovations. Today the innovation process becomes increasingly 'open', involving to a significant extent firm's customers, suppliers and business partners [37–39]; for this purpose among them should be exchanged initially ideas and then structured documents (e.g. with designs of new products, and later with demand and production plans), and this can be facilitated and supported by the interoperability of their IS. Inter-organizational networks, which facilitate the accelerated flows of information, resources and trust necessary to develop and diffuse innovation, have become of critical importance for innovation [44]. The above interactions can be greatly supported by IS interoperability. Also, it is of critical importance for the development and operation of various types of new business models [46,47], which create new value propositions and value production architectures. Finally, IS interoperability is a necessary infrastructure for the participation in local or international networks, such as value networks, virtual organizations and digital business ecosystems [44,45], which are highly important for exchange of knowledge and innovation. For these reasons we expect that firm's IS interoperability will increase the impact of its ICT infrastructure on its innovation activity. So our third research hypothesis is:

H3. The adoption of IS interoperability standards increases the impact of ICT on firm's innovation activity.

Finally, since the adoption of IS interoperability standards is expected – as mentioned above – to increase the impact of firm's ICT infrastructure on the performance of business processes, the value offered to customers and the innovation activity, we expect that it will increase the impact of firm's ICT infrastructure on its financial performance as well. Therefore our fourth research hypothesis is:

H4. The adoption of IS interoperability standards increases the impact of ICT on firm's financial performance.

4. Data and method

For this empirical study we used a large dataset collected in the 'e-Business Survey 2006', which was conducted by the European e-Business Market W@tch (www.ebusiness-watch.org), an observatory organization supported by the DG Enterprise and Industry of the European Commission. This survey included interviews with decision-makers of 14,065 firms from 29 European countries (European Union (EU) member states, acceding and candidate countries and also countries of the European Economic Area (EEA)), which were conducted using computer-aided telephone interview (CATI) technology. They were based on a structured questionnaire with a large number of closed questions concerning the usage of various types of ICT infrastructures and applications, impact of ICT, innovation activity and business performance. In Appendix A we can see the specific questions we used from the above questionnaire for this study. The target population of this survey included all firms of the above countries which are active in one of the following ten selected highly important economy sectors (covering both manufacturing and services): food and beverages (S1), footwear (S2), pulp and paper (S3), ICT manufacturing (S4), consumer electronics (S5), shipbuilding and repair (S6), construction (S7), tourism (S8), telecommunication services (S9) and hospital activities (S10). A stratified sample by company size and sector was randomly selected from this population, including a 10% share of large firms (with 250+ employees), a 30% share of medium sized firms (with 50–249 employees), a 25% share of small firms (with 10–49 employees), while the remaining 35% were micro firms (with less than 10 employees). In each of the above 29 countries the data collection was conducted by a local partner firm, which selected the local sample based on the above percentages and using official statistical records and widely recognized business directories such as Dun and Bradstreet or Hein und Partner Business Pool (both used in several countries), under the coordination of the European e-Business Market European e-Business Market W@tch.

In order to test the research hypotheses developed in Section 3, for each of the four perspectives/dimensions of business performance proposed by the balanced scorecard approach (financial, customers' value, internal business process, learning and innovation), we estimated one regression model with the specification shown below, having as dependent variable the impact of ICT on this perspective/dimension of business performance (ICT_BP):

$$\text{ICT\_BP} = b0 + (b1 \times \text{IND\_ST}) + (b2 \times \text{PRO\_ST}) + (b3 \times \text{XML\_ST}) + (b4 \times \text{INT\_IS}) + (b5 \times \text{ESAL\_IS})$$

and having as independent variables the adoption or not of industry-specific standards (IND_ST), proprietary standards (PRO_ST) and XML-based standard (XML_ST), and also the degree of development of firm's intra-organizational (internal) IS (INT_IS) and e-sales IS (ESAL_IS). Positive and statistically significant coefficients $b1$, $b2$ and $b3$ will indicate that the adoption of industry-specific standards, proprietary standards and XML-based standards respectively increase the impact of ICT on the particular perspective/dimension of business performance.

With regard to the dependent variables, the impact of ICT on financial business performance (ICT_F INP) was quantified through the average of two items (ICT_F INP1 and ICT_F INP2) assessing whether ICT had positive influence, no influence or negative influence on firm's revenue growth and productivity respectively. The impact of ICT on the value offered to the customers (ICT_CUSV) was quantified through the average of two items (ICT_CUSV1 and ICT_CUSV2) assessing whether ICT had positive influence, no influence or negative influence on the quality of customer service and the on the quality of firm's products and services respectively. The impact of ICT on business processes performance (ICT_BPRO) was quantified through the average of two items (ICT_BPRO1 and ICT_BPRO2) assessing whether ICT had positive influence, no influence or negative influence on the efficiency of business

processes and on internal work organization. Such items assessing the perceived influence of ICT on various aspects of business performance have been extensively used in previous empirical IS research (e.g. [52–54]). Finally the impact of ICT on firm's innovation activity (ICT_INNO) was quantified through the average of two dichotomous items (ICT_INNO1 and ICT_INNO2) assessing whether the firm had introduced in the last 12 months any ICT-based product/service or process innovation. These items have also previous literature support, having been used in previous empirical IS research (e.g. [56,57]. The formulas used for the calculation of the above four dependent variables are:

$$\text{ICT\_FINP} = \frac{\text{ICT\_FINP1} + \text{ICT\_FINP2}}{2}$$

$$\text{ICT\_CUSV} = \frac{\text{ICT\_CUSV1} + \text{ICT\_CUSV2}}{2}$$

$$\text{ICT\_BPRO} = \frac{\text{ICT\_BPRO1} + \text{ICT\_BPRO2}}{2}$$

$$\text{ICT\_INNO} = \frac{\text{ICT\_INNO1} + \text{ICT\_INNO2}}{2}$$

while their component items are shown in Appendix A.

Our main independent variables were three dichotomous items (IND_ST, PRO_ST and XML_ST) assessing whether the firm uses industry-specific standards, proprietary standards and XML-based standards respectively in order to exchange data with its customers and suppliers. As mentioned in Section 1 they correspond to the three main types of IS interoperability standards used today, so it is interesting to examine and compare their impacts on the contribution of ICT to above four important perspectives/dimensions of business performance.

Additionally, taking into account that the main determinants of the impact of firm's ICT infrastructure on business performance is the extent of using IS for supporting its internal processes and also its interaction with the external environment, we have included two additional relevant independent variables focusing on the two most widely used types of IS: the intra-organizational/internal and the e-sales ones. The first was the degree of development of firm's IS (INT_IS), which was quantified through the average of six items (INT_IS1 to INT_IS6) assessing whether the firm has: (a) a basic internal infrastructure: the Intranet and also (b) five important applications supporting fundamental internal functions: enterprise resource planning (ERP) system, accounting software, software for tracking working hours or production time, capacity or inventories management software and software for sharing documents between colleagues or performing collaborative work in an online environment. Such items have been used extensively in previous empirical IS research for measuring the degree of development internal IS (e.g. [56,58,59]. The second additional independent variable was the degree of development of firm's e-sales IS (ESAL_IS), which was quantified through four items (ESAL_IS1 to ESAL_IS4) assessing whether the firm uses IS for conducting four important stages of the lifecycle of a sale: for publishing offers to customers, answering calls for proposals or tenders, receiving orders from customers and enabling customers to pay online. These items have also extensive previous literature support [58,59]. The formulas used for the calculation of the above two composite independent variables are:

$$\text{INT\_IS}\,\frac{\text{INT\_IS1} + \text{INT\_IS2} + \text{INT\_IS3} + \text{INT\_IS4} + \text{INT\_IS5} + \text{INT\_IS6}}{6}$$

$$\text{ESAL\_IS}\,\frac{\text{ESAL\_IS1} + \text{ESAL\_IS2} + \text{ESAL\_IS3} + \text{ESAL\_IS4}}{4}$$

while their component items are shown in Appendix A.

Finally, in order to control for other sector-specific factors affecting the impact of ICT on business performance we also included for the abovementioned ten sectors covered by our survey nine sectoral dummies (since one sector was used as a reference group).

5. Results

The abovementioned four regression models were estimated, initially through ordinary least squares (OLS) and then through ordered probit (ordinal regression), using the PASW Statistics 18.00 SPSS statistical software package. The results with respect to the statistical significances of the independent variables were identical, which indicates their robustness. In Table 1 we can see the estimated four models using OLS, having as dependent variables the impacts of ICT on the four business performance perspectives/dimensions proposed by the balanced scorecard approach: financial performance (ICT_FINP), value offered to customers (ICT_CUSV), performance of business processes (ICT_BPRO) and innovation (ICT_INNO); for each model we can see the standardized coefficients of the independent variables, which allow a comparison of the effects of them on the dependent variable.

We remark that in all four models the standardized coefficients for all the three examined types of IS interoperability standards (variables IND_ST, PRO_ST, XML_ST) are positive and statistically significant. At the same time in all models the standardized coefficients of the degree of development of internal IS (variable INT_IS) and e-sales IS (variable ESAL_IS) are positive and statistically significant as well. Therefore we can conclude that the adoption of industry-specific standards, proprietary standards and XML-based standards for establishing IS interoperability with cooperating firms (e.g. customers, suppliers, and business partners) all increase the positive impact of ICT on the financial performance of the firm, the value offered to the customers, the performance of its business processes and the innovation activity of the firm. So all four research hypotheses H1 to H4 are supported for all the three examined types of IS interoperability standards. These results provide a strong empirical evidence of the multidimensional business value generated by IS interoperability, based on a large dataset.

It is also interesting to compare between the effects of these three types of IS interoperability standards using the corresponding standardized coefficients of the above regression models. We

Table 1
Estimated regression models of the contributions of ICT to financial performance, customers' value, business processes performance and innovation.

	ICT_FINP	ICT_CUSV	ICT_BPRO	ICT_INNO
IND_ST	0.165***	0.158***	0.156***	0.119***
PRO_ST	0.037***	0.035***	0.039***	0.043***
XML_ST	0.044***	0.030***	0.038***	0.103***
INT_IS	0.145***	0.142***	0.219***	0.173***
ESAL_IS	0.122***	0.124***	0.074***	0.176***
DUM_1	−0.118***	−0.062***	−0.063***	−0.036***
DUM_2	−0.098***	−0.052***	−0.076***	−0.032***
DUM_3	−0.080***	−0.043***	−0.026***	−0.029***
DUM_4	−0.031***	−0.016*	−0.011	0.020**
DUM_5	0.006	0.016*	−0.009	0.029***
DUM_6	−0.029***	−0.018**	0.003	−0.030***
DUM_7	−0.074***	−0.071***	−0.014	−0.068***
DUM_9	0.037	0.041***	0.017*	0.117***
DUM_10	−0.069***	−0.024***	−0.015*	0.023***
R^2	0.166	0.161	0.159	0.235

* Denotes statistical significance at the 10% level.
** Denotes statistical significance at the 5% level.
*** Denotes statistical significance at the 1% level.

remark that these effects differ significantly. In particular, we can see that the adoption of industry-specific standards leads to the highest increase of the impact of ICT on all the examined perspectives/dimensions of business performance: the corresponding standardized coefficients in the four models (0.165, 0.158, 0.156 and 0.119) are much higher than the ones of the XML-based standards (0.044, 0.030, 0.038, 0.103 respectively) and the proprietary standards (0.037, 0.035, 0.039, 0.043 respectively). This can be explained if we take into account that industry-specific standards have some characteristics that increase the generated business value:

1. As mentioned in Section 1, they have exactly the whole needed 'depth and breadth' for the particular industry, i.e. they include all the range of the required elements (even specific ones to the particular industry) of the electronic documents exchanged between a firm and its suppliers, customers, sales channels, business partners, etc. (such as orders, invoices, payments, returns, product designs, production plans, and demands); at the same time they do not carry additional elements that would serve other industries. Therefore they enable a fully automated exchange of various types of electronic documents with all the required information, without the need of conversion programmes or human interventions; this reduces significantly costs, improves efficiency and fosters innovation.
2. Also, they have high level of applicability, as they are usually adopted by most of the firms belonging to the particular industry and also their suppliers, customers, sales channels, etc. so they can be used for exchanging electronically many different business documents with most of the firms we have transaction and cooperation with (strong network effects).

On the contrary XML-based standards are characterized by even higher levels of applicability, as they are typically cross-sectoral, so they can be used for exchanging electronically business documents with firms of not only the same industry, but also other industries as well. However, as mentioned in the Introduction, they lack the needed depth for representing sector-specific characteristics and information elements, as they have been developed with a 'least common denominator' logic, so they include mainly elements that are common across sectors, and do not provide a ''perfect match'' with needs. For these reasons the adoption of XML-based standards results in a lower increase of the impact of firm's ICT infrastructure on the examined perspectives/dimensions of business performance in comparison with the industrial standards.

Finally, the proprietary standards usually have extensive 'depth and breadth', but cover mainly the requirements (documents and elements) of the strong creator firm. Also, they are characterized by much lower levels of applicability, as such a standard can be used for establishing IS interoperability only with the creator firm and a small number of firms that adopt it. Usually the adoption of such a standard by a firm is not an initiative of its management, and it is imposed by a strong customer, supplier or business partner. For these reasons the adoption of proprietary standards leads to lower increase of the impact of firm's ICT infrastructure on business performance in comparison with the industrial ones.

Also, it is interesting to examine the magnitudes of the above positive effects of these three types of IS interoperability standards, by comparing them with the corresponding effects of the degree of development of firm's internal and e-sales IS, which are regarded as fundamental determinants of the business value a firm gets from its ICT infrastructure. We remark that the magnitude of the effect of industry-specific standards in the financial performance model is 114% (=0.165/0.145) of the effect of the degree of development of internal IS, which is regarded as the most important determinant of the impact of firm's ICT on business performance; the corresponding percentages in the other three models are 111% in the customers' value model, 71% in the business processes performance model and 69% in the innovation model. This indicates that the adoption of industry-specific standards for establishing IS interoperability with cooperating firms has similar effects on business performance with the degree of development of firm's IS. This indicates that the adoption of industry-specific standards by a firm for establishing IS interoperability with other cooperating firms has similar importance with the degree of development of its internal IS.

We can make a similar comparison with the effects of e-sales IS. We remark that the magnitude of the effect of industry-specific standards in the financial performance model it is 135% (=0.165/0.122) of the effect of the degree of development of its e-sales IS, which is regarded as another highly important and beneficial type of IS increasingly used by firms; the corresponding percentages in the other three models are 127% in the customers' value model, 211% in the business processes performance model and 68% in the innovation model. This indicates that the adoption of industry-specific standards for establishing IS interoperability with cooperating firms has stronger effects on business performance (with the only exception of innovation performance) than the degree of development of firm's e-sales IS.

Finally, we remark that most of the coefficients of the sectoral dummies are statistically significant, which indicates that there are sector-specific factors that affect the impact of ICT on business performance, and this makes the inclusion of sectoral dummies in such regressions necessary.

6. Conclusions

Previous research has identified and discussed various dimensions of business value generated by IS interoperability, however empirical testing and investigation of them has been quite limited. Responding to this challenge in the previous sections has been presented an empirical investigation of the business value generated by the adoption of IS interoperability standards along the four business performance dimensions proposed by the well-established balanced scorecard approach [6–9], based on a large dataset. It has been concluded that the adoption of industry-specific standards, proprietary standards or XML-based standards for establishing IS interoperability with cooperating firms (e.g. customers, suppliers, and business partners) all increase the positive impact of ICT on the financial performance of the firm, the value offered to the customers, the performance of its business processes and the innovation activity of the firm. These conclusions are in the same direction with the ones of the few previous empirical studies on IS interoperability business value, which have found that the adoption of IS interoperability standards results in business benefits of both operational and strategic nature [50], and also reduces the effort required for B2B integration of IS [51]; however, our study has examined a wider range of business performance perspectives/dimensions, including innovation performance, and is based on a much larger dataset collected from firms of 25 European countries.

Another useful contribution of our study is that it has compared the three main types of IS interoperability standards as to their effects on the above four business performance dimensions; this revealed significant differences among them. In particular, the adoption of industry-specific IS interoperability standards has much higher impacts on the above business performance dimensions than the adoption of XML-based or proprietary standards; this is due to a combination of useful characteristics that the industrial standards possess: they have on one hand exactly the whole needed ''depth and breadth'' for the particular

industry, and on the other hand high level of applicability, which result in higher levels of business value generation.

Another interesting contribution of this study is that it assesses the magnitudes of these positive effects of the examined types of IS interoperability standards in a 'pragmatic' manner, by comparing them with the corresponding ones of the 'classical' determinants of ICT business value at firm level: the degree of development of firm's intra-organizational/internal and e-sales IS. We have found that the effects of the industry-specific IS interoperability standards are quite strong, being of similar magnitude with the corresponding effects of the degree of development of the internal IS, and of higher magnitude than the corresponding effects of the degree of development of the e-sales IS. The above results provide valuable empirical evidence of the multidimensional business value generated by IS interoperability, its big magnitude and its strong dependence on the type and the characteristics of the IS interoperability standards adopted.

Our study has interesting implications for IS research and management. It provides a framework for future empirical research on the business value of various IS interoperability architectures, frameworks, methods and standards, which is based on the well-established balanced scorecard approach; also, this framework allows a comparison of the business value generated by various IS interoperability architectures, frameworks, methods and standards with the business value generated by the development of various types of IS (which are regarded as the main ICT value generators). Furthermore, the strength of the effects of adopting such standards on financial, operational and innovation performance of firms indicates that future research on IS business value should take into account the levels of interoperability that firm's ICT infrastructures provide as highly important variables. With respect to IS management practice, our conclusions indicate that it is necessary to put strong emphasis not only on developing the functionality and capabilities of firm's IS of various types, but also on establishing interoperability of them with the ones of other cooperating firms, taking into account the high business value that IS interoperability generates. However, since IS interoperability is an infrastructure, which facilitates and drives various advanced and highly beneficial business practices (such as the ones discussed in Section 2), the level of business value it generates depends on the extent of exploiting the above capabilities offered by IS interoperability for introducing these practices. But this is out of the control of IS management, as it is responsibility of other departments' management to decide on the introduction or not of such practices. Therefore IS management should develop good relations and systematic collaboration with the management of the other departments, so that they can examine together the advantages and disadvantages of introducing such practices by exploiting the capabilities offered by IS interoperability. Finally, in order to maximize IS interoperability business value IS managers should select and adopt appropriate standards characterized by extensive 'depth and breadth' (i.e. cover all required business documents and elements) and also wide applicability.

Further empirical research is required on the business value that IS interoperability generates, examining various existing IS interoperability architectures, frameworks, methods and standards. It is important to investigate empirically the business value not only of the 'technical' interoperability, but also of the 'organizational' interoperability as well, and their complementarities. Furthermore, it is necessary to understand better the mediators of the relations between various IS interoperability architectures/frameworks/methods/standards adoption and business performance. In this direction it would be useful to examine the mediating role in these relations of the advanced business practices facilitated by IS interoperability, which have been mentioned in Section 2 (e.g. using structural equations modelling techniques); this would enable a better understanding of how IS interoperability business value is generated and how it can be increased.

Appendix A

Survey questions used for measuring the dependent and independent variables.

Variable	Items
Impact of ICT on financial performance (**ICT_FINP**)	**ICT_FINP1**: has ICT had a positive, negative or no influence on revenue growth? **ICT_FINP2**: has ICT had a positive, negative or no influence on the productivity of your company?
Impact of ICT on value offered to customers (**ICT_CUSV**)	**ICT_CUSV1**: has ICT had a positive, negative or no influence on the quality of customer service? **ICT_CUSV2**: has ICT had a positive, negative or no influence on the quality of your products and services?
Impact of ICT on business processes performance (**ICT_BPRO**)	**ICT_BPRO1**: has ICT had a positive, negative or no influence on the efficiency of your business processes? **ICT_BPRO2**: has ICT had a positive, negative or no influence on the internal work organization of your company?
Impact of ICT on innovation (**ICT_INNO**)	**ICT_INNO1**: during the past 12 months have you launched any new or substantially improved product or services directly related to or enabled by information or communication technology? **ICT_INNO2**: during the past 12 months have you introduced any new or substantially improved internal processes directly related to or enabled by information or communication technology?
XML-based standards adoption (**XML**)	Do you use **XML**-based standards for exchanging data with your buyers and suppliers?
Industry-specific standards adoption (**IND_ST**)	Do you use industry-specific standards for exchanging data with your buyers and suppliers?
Proprietary standards adoption (**PRO_ST**)	Do you use proprietary standards for exchanging data with your buyers and suppliers?
Internal IS degree of development (**INT_IS**)	**INT_IS1**: do you use an Intranet? **INT_IS2**: do you use an ERP system (that is enterprise resource planning system)? **INT_IS3**: do you use accounting software (other than a spreadsheet)? Do you use online applications **INT_IS4**: to share documents between colleagues or to perform collaborative work in an online environment? **INT_IS5**: to track working hours or production time? **INT_IS6**: to manage capacity or inventories?
E-sales IS degree of development (**ESAL_IS**)	Do you use IT solutions for: **ESAL_IS1**: publishing offers to customers? **ESAL_IS2**: answering calls for proposals or tenders? **ESAL_IS3**: receiving orders from customers? **ESAL_IS4**: enabling customers to pay online for ordered products or services?

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