AN EMPIRICAL INVESTIGATION OF THE IMPACT OF ICT ON INNOVATION IN EUROPEAN HOSPITALS

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Abstract

Hospitals have been making significant investments in information and communication technologies (ICT) for long time. Therefore it is important to investigate their effects on various dimensions of hospitals' performance, such as their innovation performance. However, there is a lack of empirical investigations of the impact of ICT on innovation in this important industry using large datasets. This paper makes a twofold contribution in this direction. First, it investigates empirically the impact of ICT on product and process innovation in European hospitals, based on data for 743 hospitals from 18 European countries collected in the course of the e-Business Survey of the European Union. Second it uses multiple independent ICT-related variables, associated with ICT investment, budget and personnel, and also with the use of specific ICT applications and standards, both healthcare-specific and general ones, investigating their effects on product and process innovation. Our results provide evidence of positive impact of ICT on hospitals' innovation, which is however not homogeneous across all types of ICT applications: it is mainly applications enabling the exchange of data and knowledge between different functions/departments of the hospital, and with external environment, that impact positively innovation.

Keywords: information and communication technologies (ICT); innovation; hospitals.

1 Introduction

Hospitals began investing in information and communication technologies (ICT) already in the 1960s. They were used initially to support auxiliary functions, such as financial services, and subsequently to support important clinical activities, mainly to manage pharmacy, laboratory and radiology service lines (McCullough 2008; Lee et al. 2012). The respective ICT applications facilitated important services, such as drug interaction controls, laboratory quality controls and documentation of patient's radiology records. These systems were quite widespread among USA hospitals by 2000 (McCullogh 2008). Two further important technologies that were later developed were electronic medical record (EMR) systems and computerized physicians (or 'providers') order entry (CPOE) systems (the latter enable the electronic entry of medical practitioner orders for the treatment of patients, which are then communicated over a computer network to the medical staff of the pharmacy, laboratory and radiology departments responsible for fulfilling these orders). The development of EMR has greatly expanded the automation of clinical services. These systems integrate information from pharmacy, radiology and laboratory in a way that allow physicians to have a complete picture of a patient. The technology of CPOE is aiming at reducing communication errors and serving as a platform for treatment guideline automation. The combined use of these two technologies aimed to "standardize

care and reduce errors, thus enhancing both clinical quality and productivity" (Lee et al. 2012, p.8). These two technologies have been investigated by a series of USA studies with respect to the determinants of their diffusion (e.g., Cutler et al. 2005; McCullough 2008) as well as their impact on clinical quality and productivity (see the literature review in next section). Also Jha al. (2008) examined health ICT adoption, particularly adoption of EMR, in seven countries (USA, Canada, Australia and New Zealand, and also three European countries – Germany, Netherlands and the UK), and found that many of them have achieved high levels of ambulatory EMR adoption, but lagged with respect to hospital adoption of this technology. However, the authors mentioned that they "found almost no high-quality, reliable data on Electronic Health Records in acute care settings from any of seven counties" (p. 850). Since then the data situation in Europe has improved. The data used in this study show that the percentage of hospitals in 18 European countries firms using Medical Records Management Systems and CPOE amounted to 67.4% and 33.7%% respectively in 2005 (see Table 3 in section 5) (for a descriptive study on the diffusion of some ICT uses in European hospitals that is based on the same data as this study see Mikalef and Batenburg (2011) and also European Commission (2007); also, for a study on national eHealth infrastructures in European countries see Stroetmann et al. (2011)). The endowment with ICT has by now reached in Europe a level that allows to investigate possible effects of ICT use on various dimensions of the performance in European hospitals, such as the innovation performance.

ICT are regarded as important drivers of innovation in healthcare. In the literature are mentioned and analysed both successful cases of innovations driven by ICT in healthcare, and also failed ones, however, there is a lack of empirical investigations of the impact of ICT on innovation in this important industry using large datasets (see next section for more details), which would allow drawing more sound conclusions on this question. This study contributes to filling this critical research gap, investigating the impact of the use of modern ICT on innovation in European hospitals, based on a large dataset. In particular, it makes a twofold contribution in this direction:

- It investigates empirically the impact of ICT on product and process innovation in European hospitals, based on data for 743 hospitals from 18 European countries collected in the course of the e-Business Survey of the European Union; it is to the best of our knowledge the first comprehensive study of this kind for European hospitals.

- It uses multiple independent ICT-related variables, associated with ICT investment, budget and personnel, and also with the use of specific ICT applications and standards, both healthcare-specific and general ones, investigating their effects on product and process innovation.

The paper is structured as follows. The following section 2 deals with the conceptual background and research hypotheses. In the next two sections 3 and 4 are described the data and the model specification respectively. Then the results of the econometric analysis are presented in section 5, while in the final section 6 the conclusions are summarised.

2 Conceptual background and research hypotheses

2.1 Innovation in the health sector

The existing literature on innovation activities in hospitals is scarce. There are at least two reasons for that: first, conceptual difficulties to apply on the health sector the standard innovation definition that has been primarily developed for technological novelties in manufacturing, and second, the lack of innovation data for hospitals. Djellah and Gallouj (2007) in their survey article state that existing studies on hospital innovation are case studies, but there are no comprehensive studies based on larger samples of hospitals (the same authors provide an analytical concept of innovation in hospitals, which is too abstract to be easily operationalized in empirical studies (Djellah and Gallouj 2005); for a

conceptual approach specific to "innovation in healthcare" see Thakur et al. (2012)). An operationable concept of hospital innovation that remains quite close to standard innovation concept was developed in a project financed by the European Union and was applied in case studies from five countries (Ireland, Netherlands, Spain, Sweden and UK) (Cunningham 2005). This concept has also stimulated the definition of hospital innovation that was used in a Swiss survey in 2011 (Arvanitis et al. 2013a). In that study, product innovation refers to pharmaceutical and biomedical novelties (e.g., new drugs, tracers), technical novelties (e.g., equipment for Magnetic Resonance Imaging (MRI), infusion pumps, implants) and surgical and/or therapeutic methods. Process innovation in hospitals comprehends primarily ICT-driven and organizational innovations, such as changes of workplace organization, horizontal integration of departments, etc. The innovation concept used in the present study (and also in the E-business Survey 2006; see section 3) covers – in analogy to the concept of the Community Innovation Surveys – new products, services and processes that are either new for a certain hospital and/or new for hospitals in a certain country or even worldwide.

The only empirical study investigating explicitly the innovation performance of hospitals is the study of Salge (2012). It is based on data for 153 public hospitals in the UK. The main findings were that differences as to innovation performance among the hospitals can be explained by firm size, the availability of resources and different "strategical aspirations" of hospital management. However, ICT has not been taken explicitly into consideration in this study. There is no study that deals with the effects of ICT on hospital innovation, which is the main topic of this paper.

Other existing studies on innovation in hospitals deal mostly with the adoption of specific new medical technologies. For example, Grebel and Wilfer (2010) analyzed the decision process of medical services providers for adopting "cardiological technologies"; Garcia Goni (2005) examined the adoption of organizational and technological innovations in a public hospital in Spain; Yang and Hsiao (2009) investigated mechanisms for developing innovative information-enabled services in Taiwanese healthcare service.

2.2 ICT and innovation

Kleis et al. (2012) argue that the use of ICT supports and contributes to firms' innovation activities through three main channels. The first channel goes through the improvement of the management of the data and knowledge used in the innovation process. These data and knowledge might be internally created or externally acquired. Information technology enables an efficient storage and a high accessibility of these data and knowledge throughout an enterprise. Internal networks, e-mail systems, and electronic databases all facilitate the transfer of data and knowledge and the communication between innovation participants. This is particularly the case for external information, which is critical for successful innovation. (Klevorick et al. 1995; Laursen and Salter 2006). Second, ICT enables a more efficient cooperation in innovation with external partners. The creation of new knowledge through collaboration with other firms has become more and more important in the last twenty years (Enkel et al. 2009). Information technology facilitates the exchange of information with external partners that are located far away from the focal firm. Third, ICT contributes directly to the innovation production in several ways. Kleis et al. (2010) identified three main stages of the innovation process, for which the application of ICT has proved to be useful. First, the stage of the generation of ideas for new products can benefit from information systems that enable a firm to analyze customers' communication and transaction data (e.g., Customer Relationship Management (CRM) systems) and identify needs that can be covered by new products or significant modifications of existing products. Further, information technology enables the development of efficient design capabilities for new products. For example, technologies such as computer-aided design (CAD) and computer-aided manufacturing (CAM) help to digitize a new product's design, make it available throughout the innovation process. Finally, ICT helps integrate design and production systems, so that errors of

information transfer and translation are reduced and, as a consequence, the efficiency of this last stage of the innovation process is increased.

Furthermore, ICT can also directly drive ICT-based innovations in firms' processes, products, services, and even business models (Tapscot et al. 2000; Brynjolfsson and Hitt 2000; Bresnahan et al. 2002; Brynjolfsson and Saunders 2010). According to Bresnahan et al (2002) ICT can change dramatically the way human work is performed, measured, controlled and reported, and enable significant restructuring of it, by allocating routine, well-defined tasks associated with symbols processing to computers, radically transforming tasks that require human skills, changing their requence, and also eliminating some others making them unnecessary. Also, ICT enable an individual employee to have all the required information for completing a bigger part of a process, so the existing for long time excessive fragmentation of many processes can be dramatically reduced, resulting in large efficiency gains. Furthermore, Brynjolfsson and Saunders (2010) argue that ICT can directly drive and enable new products and services, and increased products' and services' variety and personalization, which would not be operationally and economically feasible without ICT, and also significant quality improvements, improved timeliness, and other quality characteristics highly valued in modern economy.

A brief review of the limited empirical literature on the impact of ICT on innovation can be found in Arvanitis et al. (2013b). These emprical studies are all based on cross-sectoral samples, so there is a lack of empirical investigations of the impact of ICT on innovation in the healthcare industry; our study contributes to filling this critical research gap.

2.3 Research hypotheses

Based on the previous section we can formulate two research hypotheses concerning the impact of ICT on process and product innovation in hospitals. ICT can lead to significant innovations in the processes of the main hospital's functions, such as patients administration, clinics, pharmacies, laboratories, etc. In particular, it can drive improvements, simplifications and standardization of them, by enabling automated execution of some of their tasks, transformation of some others, or changes in their sequence (e.g. allowing previously serial tasks to be executed in parallel), or even eliminating some tasks (e.g. making some check tasks unnecessary) (Bresnahan et al. 2002). Also, some healthcare-specific applications (e.g. CPOE, medical images archiving and transmission), and also some general ones (e.g. ERP), can improve integration and coordination between different departments (e.g. between clinics and laboratories the former, or between financial departments and clinics the latter), and lead to the establishment of new horizontal processes and introduce new work organization and practices (Lee et al. 2012). Furthermore, such applications will result in the collection and integration of large quantities of data, the analysis of which might reveal significant weaknesses and problems of existing processes (e.g. through the calculation of appropriate analytics), resulting finally in innovative changes of them. Moreover, the development of ICT systems which are interoperable with the ones of cooperating organizations (e.g. other hospitals or health centers, suppliers, etc.) can lead to significant innovations in the processes of cooperation and transaction with them (Loukis and Charalabidis 2013). For the above reasons we expect that ICT will have a positive impact on process innovation in hospitals. So, our first research hypothesis is:

Hypothesis 1: ICT has a positive impact on process innovation in hospitals.

Also, according to innovation literature the exchange and combination of data and knowledge between various functional domains of an organization, and also with other organizations (both from the same sector and from other sectors), are of critical importance for product innovation (Nerkar and Paruchuri 2005; Castellaci 2008; Zeng et al. 2010). So the exchange of data between different functions and departments of a hospital that various healthcare-specific applications (e.g. CPOE, medical images archiving and transmission) and also general ones (e.g. ERP) allow, will have a positive impact on product innovation, as it will promote the generation of innovative ideas concerning the introduction

of various pharmaceutical, therapeutic or biomedical novelties, and also will enable the cost-efficient implementation of them. Also, the development of ICT systems which are interoperable with the ones of cooperating organizations, such as other hospitals or health centers, suppliers, etc., will facilitate the exchange of data and knowledge among them, so it will be another important source of such innovative ideas, and a strong facilitator of their implementation. The use of CRM systems allows collecting valuable data about patients' needs, which can also lead to important product innovations. In general, ICT can enable the development of new products, and also higher levels of variety and personalization of existing ones, which would not be operationally and economically feasible without ICT. For the above reasons we expect that ICT will have a positive impact on product innovation in hospitals. So, our second research hypothesis is:

Hypothesis 2: ICT has a positive impact on product innovation in hospitals.

3 Data

The data we used in this study come from the e-Business Survey 2006 of the European Union. The survey covered all members of the European Union (EU-25) plus Norway and Turkey, and ten sectors, among them healthcare (hospitals). It was based on a questionnaire that contained in ten modules of questions on ICT infrastructure, e-skills, ICT expenditure, internal and external e-collaboration, online procurement, online sales, use of e-standards and interoperability issues, impacts of ICT, innovation activity and general characteristics of the surveyed entities (such as number of employees, employees' formal qualification, year of foundation as well as various measures of neconomic performance). Interviews were carried out based on this questionnaire using computer-aided telephone interview (CATI) technology, normally with the person responsible for ICT within the hospital/enterprise. Alternatively, particularly in small hospitals, the managing director was interviewed. The survey included only hospitals/enterprises that used computers. The sample was drawn randomly from the respective sector population in each of the countries considered, with the objective of minimum strata with respect to size class per country-sector cell. The response rate, i.e. the number of completed interviews divided by the net sample of contacts established with eligible hospitals/enterprises, was typically about 15-20%, with, however, big differences in some of the countries. For this study we used the subset for hospitals that contained information for 18 countries. From the originally 932 observations (about 5% of all European hospitals) we excluded those hospitals with less than 10 employees in order to allow for some minimum size that implies a wider spectrum of activities. Due to missing values for some variables the dataset that was used for the econometric estimates contained 678 observations. About 70% of all hospitals in our sample are general hospitals that have several medical departments, and the reamining 30% are specialized ones (e.g., pediatric clinics). As to owner status, about 43% of them are public hospitals, about 43% private profit-oriented hospitals and only 13% non-profit private ones. About 28% are large hospitals with 500 employees and more. Only 16% are small clinics or regional medical stations with 10 to 49 employees.

4 Model specification

The dependent and independent variables of our study are shown in Table 1. As dependent variables for the innovation equations we use two binary variables, one for product innovation (INNOPD) and a second one for process innovation (INNOPC). As independent variables we use a group of ICT-related variables and also a group of control variables for several characteristics of hospitals that might be relevant for innovation. The first group, which is the more important one, consists of a series of ICT-related variables that cover a wide spectrum of elements of the hard and soft ICT infrastructure of a

hospital. In particular, the variables 'ICT-investment', 'ICT-budget' and , 'ICT-personnel' capture various aspects of the resource endowment in ICT, while the variables 'E-business' and 'website' refer to two important types of ICT systems aiming at communication with the external environment. Eight further variables refer to the use of important ICT applications. Some of them are specific to health sector, namely 'Patient Administration System' (ICT_appl1); 'Picture Archiving and Communication - Medical Image Transmission System' (PACS) (ICT_appl2); 'Pharmacy Management System' (ICT_appl3); and 'Computerized Physician Order Entry System)(CPOE) (ICT_appl4) and 'Medical Records Management System' (ICT_appl6); some others are of more general (cross-sectoral) use such as 'Intranet' (ICT_appl5); 'Enterprise Resource Planning System' (ERP) (ICT_appl7) and 'Customer Relationship Management' (CRM) (ICT_appl8). The use of the above multiple ICT-related variables allow investigating whether various aspects of the resource endowment in ICT impact process and product innovation in hospitals, and also which types of ICT-applications yield significant effects on innovation and which do not.

Variables	Definition
Dependent variables	
INNOPD	Introduction of new or substantially improved products or services in the past 12 months: yes/no
INNOPC	Introduction of new or substantially improved internal processes in the past 12 months: yes/no
Dependent variables	
R&D	Employees conducting research and development: yes/no
ICT_personnel	Employment of ICT practitioners: yes/no
ICT_investment	Investment in ICT (for new hardware, software or networks) in the past 12 months: yes/no
ICT_budget	Increase of ICT budget in the past 12nmonths: yes/no
Website	Website on the internet: yes/no
E-business	E-business is a significant part of the way a hospital operates: yes/no
ICT_appl1	Use of Patient Administration System: yes/no
ICT_appl2	Use of Picture Archiving and Communication - Medical Image Transmission System (PACS): yes/no
ICT_appl3	Use of Pharmacy Management System; yes/no
ICT_appl4	Use of Computerized Physician Order Entry System (CPOE); yes/no
ICT_appl5	Use of Intranet: yes/no
ICT_appl6	Use of Electronic Medical Records Management: yes/no
ICT_appl7	Use of Enterprise Resource Planning System (ERP): yes/no
ICT_appl8	Use of Customer Relationship Management (CRM): yes/no
ICT_interoper1	Use of XML-based standards: yes/no
ICT_interoper2	Use of Health Level 7 standard: yes/no
ICT_competition	Increase of competition in the health sector due to ICT: yes/no
General hospital	General hospital: yes/no; reference: specialized hospital
Public hospital	Public hospital: yes/no; reference: private hospital
Non-profit hospital	Non-profit hospital; reference: private hospital
Founded after 1981	Founded before 1981: yes/no
Dummies for hospital size	Dummies for 5 size classes (number of employes); reference: 10 to 49 employees
Country dummies	Dummies for Belgium, Czech Republic, Germany, Greece, Spain, France, Italy, Latvia, Lithuania, Hungary, Netherlands, Poland, Portugal, Finland, Sweden, Turkey, Norway; reference: United Kingdom

Table 1. Definitions of variables

Finally, we also included two measures of the interoperability of hospitals' ICT systems with the ones of other cooperating organizations, as previous literature has emphasized that it can significantly increase both the efficiency and innovation benefits obtained from ICT (e.g. see the empirical study of Loukis and Charalabidis (2013), which is based on a mixed cross-sectoral dataset); they concern the use of two most important and widely used categories of standards: 'XML-based standards' (='horizontal' standards that can be used for exchanging data with organizations of any sector, so they are not customized to the needs of any particular sector), and 'Health Level 7 standard' ('vertical' standards that can be used for exchanging data within the healthcare sector, so they are customized to the needs of this sector - see www.hl7.org). The controls included variables for the (ICT-driven) competition conditions among hospitals, the R&D activity of the hospital, the type of hospital (general or specialized), the ownership status (public, non-profit, private), the hospital age, the size of the hospital and the country in which a hospital is located.

5 Results

5.1 Descriptives

Table 2 presents information on the frequency of use of the above ICT applications and interoperability standards in European hospitals. With respect to the healthcare-specific applications we remark that some of them are quite widespread (Patient Administration, Electronic Medical Records Management and Pharmacy Management Systems), while some more advanced ones (Computerized Physician Order Entry (CPOE) and Picture Archiving and Communication - Medical Image Transmission Systems (PACS)) are used only by a rather small share of hospitals. From the examined general applications, two are widely used (Website and Intranet), while the others (e-business, ERP and CRM) are used only to a limited extent. Finally, there is a low level of adoption of both XML-based (horizontal) and HL7 (vertical for the health sector) standards.

ICT applications	N	Percentage
Heathcare-specific:		
Patient Administration System	600	80.8
Picture Archiving and Medical Image Transmission Systems (PACS)	246	33.1
Pharmacy Management System	437	58.8
Computerized Physician Order Entry (CPOE)	250	33.7
Electronic Medical Records Management	501	67.4
General:		
Website	558	75.1
e-business	181	24.4
Intranet	454	61.1
Enterprise Resource Planning System (ERP)	224	30.2
Customer Relationship Management (CRM)	82	11.0
Interoperability standards		
XML-based standards	167	22.5
HL7 standards	171	23.0

Table 2. Frequency of various ICT applications and interoperability standards in European hospitals

5.2 Econometric issues

Activities directed to product innovation and those aiming at process innovation are closely related (e.g., see Athey and Schmutzler (1995) for a theoretical justification of this close complementary relationship; Kraft (1990); and Rouvinen (2002) for empirical evidence). In order to take this interdependence into account we estimated a bivariate probit model for the binary variables INNOPD and INNOPC.

Due to the cross-section character of our data, both the left-hand and the right-hand variables refer to the same time period. As a consequence, our estimates of the innovation equations have to be seen primarily as an extensive analysis of the correlations between the determinants (that are considered as structural characteristics that change only slowly over time) and the innovation indicators, respectively. Nevertheless, some robust regularities come out, which if interpreted in view of our hypotheses presented in section 2 could possibly indicate the direction of causal links.

5.3 Innovation equations

In Table 3 we can see the bivariate probit estimates for the product and process innovation equations specified in section 4 (we made an initial estimation of these models, then we removed the independent variables not having statistically significant effects in any of these two models, and we repeated models' estimation without them, and these final models are shown in Table 3). The overall picture that emerges from our estimates is that ICT-related factors are closely related with the innovation performance of European hospitals. However, there are also some differences between ICT-related factors affecting product and process innovation. The high correlation between the two innovation equations (rho=0.530) seems to justify the application of multivariate probit as the appropriate econometric method in order to take into account the interdependence between these two forms of innovation.

In particular, we remark that a strategy of further expanding the ICT-infrastructure through additional investment in hardware, software or networks (variable ICT_investment) shows a significantly positive effect on the propensity of both product and process innovation. The increase of the effective ICT-budget (variable ICT_budget), which is used not only for ICT investment, but also for ICT operating expenses as well, appears to have a positive effect, particularly on process innovation that mostly requests larger ICT operating expenses than product innovation. The impact of ICT-infrastructure on innovation is not directly associated with the employment of ICT specialists (variable ICT_personnel). This is not in agreement with previous empirical literature (which is however based on mixed cross-sectoral datasets) concluding that the employment of ICT personnel increases considerably the positive effects of ICT infrastructures on innovation (e.g. Arvanitis et al. 2012). Presumably, the ICT personnel of hospitals focuses mainly on the efficient operation of their ICT-infrastructures, and not on exploring novel ways of exploiting them for promoting product or process innovation, which in this sector requires mainly extensive medical knowledge and expertise, so medical personnel might be more well positioned and appropriate for this and influential. The existence of a website (variable Website) is not important for innovation, but external links mostly for on-line sourcing and exchange of information and knowledge (variable E_business) seem to be relevant for both forms of innovation.

	INNOPD	INNOPC
R&D	0.199	0.202*
	(0.128)	(0.124)
ICT_personnel	0.081	0.116
	(0.121)	(0.123)
ICT_investment	0.538***	0.304*
	(0.153)	(0.160)

ICT-budget	0.091	0.272**
	(0.118)	(0.118)
Website	0.040	0.061
	(0.144)	(0.147)
E-business	0.235*	0.292**
	(0.126)	(0.137)
ICT_appl2	0.222*	0.303**
	(0.125)	(0.130)
ICT_appl4	0.355***	0.378***
	(0.131)	(0.133)
ICT_appl7	0.068	0.307***
	(0.129)	(0.127)
ICT_appl8	0.489***	0.029
	(0.175)	(0.178)
ICT_interoper1	-0.010	0.282**
	(0.141)	(0.140)
ICT_interoper2	0.388**	0.253*
	(0.161)	(0.153)
ICT_competition	0.266**	0.357***
	(0.118)	(0.119)
General hospital	0.203	-0.180
	(0.132)	(0.132)
Public hospital	-0.186	-0.045
	(0.166)	(0.162)
Non-profit hospital	-0.021	-0.082
	(0.197)	(0.186)
Founded after 1981	-0.102	-0.058
	(0.126)	(0.128)
50–99 employees	0.070	0.072
	(0.213)	(0.206)
100 – 199 employees	-0.038	0.119
	(0.204)	(0.197)
200 – 499 employees	0.007	-0.082
	(0.210)	(0.208)
500 – 999 employees	-0.008	-0.094
	(0.253)	(0.248)
1000 employees and more	-0.024	-0.147
	(0.261)	(0.262)
Country dummies	Yes	Yes
Const.	-1.704***	-1.381***
	(0.359)	(0.345)
N	678	
Wald chi2	324.9***	
Rho	0.530	
Wald chi2 test of rho = 0	66.4***	

*Note:*Heteroskedasticity-robust standard errors in brackets; ***. **, * denote statistical significance at the 1, 5 and 10% level;
reference‘general hospital’: ‘specialized hospital’;
reference ‘public’ and non-profit’: private; reference hospital size: 10 - 49 employees.

Table 3. Estimated product and process innovation equations

Furthermore, we can see that the use of four of the examined ICT-applications is positively correlated with either product or process innovation, or with both of them. In particular, two hospital-specific ICT applications, ICT_app2 - PACS (Picture Archiving and Communication System) and ICT_app4 - CPOE (Computerized Physician Order Entry) are relevant for both product and process innovation. Both these applications allow the exchange and combination of data and knowledge between personnel of different functions/departments of the hospital, which is according to the literature of critical importance for product innovation (e.g. Nerkar and Paruchuri (2005)). Also, they enable a better horizontal cooperation and coordination between different mainly medical functions-departments, so they drive innovations in these processes. In particular, CPOE enables physicians' orders for various examinations to be automatically transmitted electronically – through hospital's internal network – to the corresponding hospital laboratories; this on one hand eliminates previous lengthy, problematic (e.g. because of faults and losses) and inefficient paper-based processes followed for this purpose, and on the other hand allows a better planing of laboratories' work and resources exploitation; also, CPOE enables the results of these examinations to be transmitted back to the physicians electronically, and possibly stored in patient's electronic medical record as well, so that the appropriate medical actions can be taken much quicker than before; these can resulting finally in higher efficiency and effectiveness. Similarly, PACS allow the pictures produced from various medical examinations to be centrally archived and linked with patient's electronic medical record, so they are directly accessible by clinics and physicians throughout the hospital, in order to be exploited to the largest possible extent for supporting medical decisions (e.g. concerning patient's optimal therapy); this can also result in higher efficiency and effectiveness.

Furthermore, two ICT applications of general (cross-sectoral) use are positively correlated with innovation: ICT_app7 - ERP (Enterprise Resource Planning System) is important for process innovation, while ICT_app8 - CRM (Customer Relationship Management) is important for product innovation. This is in accordance with the specific application fields of these technologies. Both these applications provide economical storage of and convenient access to information by hospital personnel of various different specialities, functions and departments, which – as mentioned above - promotes innovation (Nerkar and Paruchuri 2005). ERP systems serve to organize and coordinate different fields of activities (administrative and medical ones), so they constitute a basis for organizational processes innovation, which is quite important for hospitals. They enable a better horizontal cooperation and coordination mainly between administrative functions-departments, so they drive innovations in these administrative processes. On the contrary, CRM systems enable the collection of valuable data about patients' needs, and also organize better the relations with them, so they lead to important product innovations. It is not astonishing that pure applications that support primarily administrative and managerial tasks of a single department, such as Patient Administration and Pharmacy Management systems, do no contribute to innovation performance.

Another interesting finding is that the establishment of interoperability of hospitals' ICT systems with the ones of other cooperating organizations, through the adoption of interoperability standards, has positive effects on innovation. This interoperability facilitates the exchange of documents, data and knowledge with other organizations, which according to the literature promotes innovation (e.g. Nerkar and Paruchuri 2005; Castellaci 2008; Zeng et al. 2010). The adoption of the 'vertical' health sector HL7 standards seems to have the strongest positive effects on both product and process innovation, while the adoption of the 'horizontal' XML-based standards has weaker effects limited to process innovation. This is presumably because HL7 standards are specific and customized for the health sector, so they cover most of the documents (both administrative and clinical) that need to be exchanged between a hospital and other organizations from this sector (e.g. other hospitals or health centers, vendors of specialised medical equipment and supplies), and include all required elements/field of them (Loukis and Charalabidis, 2013); in particular, they provide messaging and document standards for exchanging various types of clinical information (covering most medical specialities) and administrative information (https://www.hl7.org/implement/standards/). For the

above reasons the HL7 standards enable a 'deep' interoperability and extensive exchange of highly detailed both clinical and administrative data and knowledge, with the organizations that are most important for innovation, and this has a strong positive impact on both product and process innovation. On the contrary XML-based standards are horizontal (i.e. not specialised and customized for the health sector), so they enable a more 'shallow' interoperability and less detailed exchange of only administrative data and knowledge (but not at all clinical), however with more organizations; these result in a weaker impact on innovation performance, which is limited to process innovation only.

R&D activities aim to provide inputs for innovations. Therefore the existence of such activities is as expected to be positively correlated with both types of innovation. However, the respective coefficient is statistically significant only in the process innovation equation. This indicates that in the health sector product innovation requires extensive medical knowledge and expertise, so medical personnel is more well positioned and appropriate for this and influential. Also, our (ICT-specific) competition variable correlates positively with both types of innovation, in accordance with similar findings in empirical innovation studies (see Cohen (2010) for a survey of this literature).

A further interesting finding is that the size of hospitals as measured by the number of employees does not show any effect on innovation. This is not in agreement with results of similar studies for industry of business services, in which mostly a significant (positive) correlation of firm size and some innovation indicator is found (e.g., see Arvanitis (2008)). Therefore scale does not seem to be particularly important for innovation in hospitals.

Finally, since all our ICT-related independent variables are binary (yes/no, in the same scale 0/1), we can use their coefficients in the two models for comparing their effects on product and process innovation. From the product innovation model (second column of Table 3) we remark that there are six ICT-related factors that have a positive effects on it. The adoption of a general strategy of further expanding the ICT-infrastructure of the hospital by increasing investment in hardware, software or networks has the strongest effect (coefficient 0.538) on product innovation, followed by the use of CRM, the adoption of HL7 standards, and the use of CPOE; lower is the innovation impact of e-business and PACS use. From the process innovation model (third column of Table 3) we remark that there is a different and wider group of eight ICT-related factors that have positive effects on process innovation. The focused strategy of using CPOE systems has the strongest effect (coefficient 0.378) on process innovation, followed by the general strategy of expansion of hospital's ICT-infrastructure by increasing ICT investment, and the focused strategies of using ERP, PACS and e-business applications; lower are the effects of XML-based standards adoption, the general strategy of higher ICT budgets and the adoption of HL7 standards.

6 Conclusions

Hospitals have been making big investments in ICT for long time, so it is has become of critical importance to examine their impacts on various dimensions of hospitals' performance; one of them – that influences all the others - is innovation performance. ICT are regarded as important drivers of innovation in healthcare. However, in the literature we can find analyses of both sucessful cases of innovations in healthcare driven by ICT, and also failed ones, but there is a lack of empirical investigations based on large datasets concerning the impact of ICT on innovation in this socially important sector, which would allow drawing more sound conclusions on this question, and provide guidance for future strategies. This study makes a twofold contribution in this direction. First, it investigates empirically the impact of ICT on product and process innovation in European hospitals, based on data for 743 hospitals from 18 European countries collected in the course of the e-Business Survey of the European Union; it is to the best of our knowledge the first comprehensive study of this kind for European hospitals. Second, it uses multiple independent ICT-related variables, associated

with ICT investment, budget and personnel, and also with the use of specific ICT applications and standards, both healthcare-specific and general (cross-sectoral) ones, investigating their effects on product and process innovation.

From our results it has been concluded that ICT has a positive impact on both product and process innovation in European hospitals, so both our research hypotheses supported. At the same time our results reveal that this positive effect is not homogeneous across all types of ICT applications. In particular, we have identified four types of applications that have positive impact either on product or on process innovation or on both of them, which however are not widely used : two of them are healthcare specific (CPOE and PACS, both having posistive impacts on product and on process innovation); the other two are more gerenal (ERP, having positive impact on process innovation, and CRM, having positive impact on product innovation). We remark that the first three of them share a common feature: they are 'inter-departmental', enabling the exchange and combination of data and knowledge between personnel of different functions/departments of the hospital and support the horizontal cooperation and coordination of them, which according to previous innovation literature promotes innovation. On the contrary, we have found that some other applications that support primarily administrative and managerial tasks of a single department, such as Patient Administration and Pharmacy Management systems, do no contribute to innovation performance. Also, our results indicate that the use of e-business applications by hospitals has positive impact on both product and process innovation. This type of application shares with the abovementioned CRM one another important feature: they enable the exchange and combination of data and knowledge with hospital's external environment, which according to previous innovation literature also promotes innovation.

Furthermore, it has been concluded that the establishment of interoperability of hospitals' ICT systems with the ones of other cooperating organizations, throught the adoption of interoperability standards, has positive effects on innovation. These effects are stronger for the 'vertical' health sector HL7 standards, since they enable a 'deep' interoperability and extensive exchange of highly detailed both clinical and administrative data and knowledge with the organizations that are highly important for innovation (e.g. other hospitals/health centers, vendors of specialised medical equipment/supplies).

Our findings have interesting implications for research and practice. With respect to future research on the impact of ICT on innovation (in the health sector and in other sectors as well) our findings indicate that it should not view ICT as a single entity, but should on the contrary discriminate between various aspects of it, such as different types of ICT applications and interoperability standards, which might have quite different effects on innovation. Our study provides a framework in this direction. With respect to hospital management, in order to increase the effect of ICT on innovation, should on one hand adopt a general strategy of further expanding the ICT-infrastructure of the hospital through sufficient ICT investment, and on the other hand adopt more focused strategies of adopting some particular types of ICT applications, which enable and facilitate the exchange of data and knowledge between different functions/departments of the hospital, and also with the external environment. Also, they should adopt appropriate vertical health sector interoperability standards providing 'deep' interoperability with most of their possible 'innovation partners'. However, the above applications and standards will not lead deterministically to more innovation, as human factors will play an important role for this; so hospital management should proceed to 'complementary actions' in this direction, such as creation of an 'innovation-friendly' atmoshere, and provision of strong motivation for this.

Of course our study has some limitations. It is a cross-section analysis and also no information on the time of adoption of various ICT applications is available. Thus, our estimates of the positive correlations of ICT-related variables with the left-hand measures of innovation can be considered as rather lower bounds of the respective effects. This is because for some hospitals that have adopted these technologies recently there has not elapsed enough time to be able to fully exploit the potential of the new technologies. It will be possible to overcome this limitation by using more cross-sections of data collected by other similar surveys of the European Union.

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