HEALTHCARE PROCESSES AND IT: EXPLORING PRODUCTIVITY GAINS THROUGH IMPROVED ALLOCATIVE EFFICIENCY

Completed Research Paper

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Abstract

The benefits of health information technology (HIT) are widely accepted. Nonetheless, how HIT becomes embedded and transforms health-care processes remain an understudied area in the literature. In this study we extend prior research by undertaking a more granular examination of HIT systems' impact on how non-IT resources are allocated to healthcare tasks and routines. The context of our research is a natural field study whereby an acute-care hospital implemented telemedicine as a tool to consult its geriatric patients. We collected and analyzed resource and patient consultation level data, both pre and post technology use to quantify possible shifts in resource allocations as well as cost efficiencies over time. Our findings suggest that HIT affords changes to non-IT resource allocations in clinical work processes which lead to changes in cost efficiencies. Depending on the nature of these non-IT resource reallocations, cost efficiencies may not always be improved.

Keywords: Healthcare Information Systems, Telemedicine, stochastic frontier analysis

Introduction

Reports by US and other international health-care IT associations have consistently recommended the implementation of health information technology (HIT) as it enables health-care organizations to provide safer, more efficient and effective health care (HIMSS 2012; Institute of Medicine 2001). Several studies on health-care and HIT have found that IT investments and use led to lower medical errors, mortality rates, and increased financial performance (Amarasingham et al. 2009; Devaraj and Kohli 2000; Devaraj and Kohli 2003). For example, studies conducted by Deveraj and Kohli (2000) found that decision support systems assisted hospitals to improve operational, managerial, and strategic decision-making. Likewise, Amarasingham et al.'s (2009) cross-sectional survey of hospitals show that clinical information systems, which automated notes and records, test results, order entry, and decision support, improved clinical outcomes. Recent research found that depending on the type of IT – clinical or administrative – health-care organizations would experience different impacts (Menon et al. 2009) and that health-care IT enabled innovative dynamic processes led to financial savings for home health-care organizations (Singh et al. 2011).

This body of research demonstrates the strong link between HIT investments and positive health-care organizational performance. Theoretically, they suggest that HIT's informational capabilities complement business process changes and are highly effective for operational and strategic decision making. In other words, they broadly argue that IT has complementarity and substitution effects on existing processes (Bresnahan et al. 2002; Devaraj and Kohli 2000; Dewan and Min 1997). While these are important insights, IS and HIT research scholars have argued that IS research need to be more precise in how HIT becomes embedded in complex health-care processes that would in turn lead to positive performances and outcomes (Davidson and Chiasson 2005; Kohli and Grover 2008). They point out that when we are more precise and explicit about the health-care context, we are better able to theorize the role HIT play in transforming clinical and non-clinical processes (Fichman et al. 2011; Payton et al. 2011). To answer this call, our study aims to explore if and how the use of HIT affects the way the health-care organization allocates its non-IT resources to work processes; and if reallocations exist, what are the impacts on cost efficiency?

Our research study contributes to HIT research in the following ways. First, our study is focused on the effects of applying a telemedicine system on the geriatric care process. By focusing on a specific type of HIT and a specific health-care process, we are able to better understand the precise manner by which the technical and organizational features of the process are changed and integrated. Second, we conducted a longitudinal field study that covered the performances before and after the implementation and use of a telemedicine system in a geriatric specialist clinic of an acute-care hospital. This natural field study design takes into account prior research which show that IT impacts depends on the actual usage of the system over a period of time (Devaraj and Kohli 2003; Menon et al. 2000).

Finally, we show that given this specific context of telemedicine-enabled geriatric care, HIT impacts are driven by allocative effects. This finding contributes to the ongoing dialog concerning the substitution and complementary effects of IT as found in earlier studies. We found that embedding telemedicine system enables the health-care organization to better allocate their non-IT resources in such a way that reduce cost and provide a better match between medical tasks and appropriate input resources. We argue that this intangible effect of allocative efficiency is not as obvious in many HIT research given that many of this research used measurements that focused on revenues, returns, and aggregated productivity measures. Our study therefore provides another model to "enhance our understanding of the various positive manifestations of IT" by taking into account another set of economic variable that has not been studied in detail at the organizational level (Kohli and Grover 2008 p.33). The rest of the paper is organized as follows. We first review the literature and highlight why a change in non-IT resource allocation might occur with HIT use. Next, we describe the research context and model. We then present the results and findings of this study. The final sections discuss the implications, limitations and our conclusions.

Theoretical Foundations and Review

In the delivery of services, cost efficiency can be achieved by either producing the maximum output with minimum input waste (i.e. improving technical efficiency) or by selecting the "right type" of input for the production of services (i.e. improving input allocative efficiency) (Kumbhakar and Lovell 2000). For example, from a technical efficiency perspective, a clinic that provides basic wound dressing services can experience high (or low) cost efficiency when the personnel performing the task are working diligently (or slowly). Similarly, from an input allocative efficiency perspective, the clinic may experience high (or low) cost efficiency if it chooses to use a registered nurse (as opposed to a higher paid physician) to do the same wound dressing tasks with comparable outcomes.

In this study we chose to predominantly focus on the possible allocative efficiency effects of HIT in health-care organizations rather than the technical efficiency effects for several reasons. First, health-care medical personnel in almost all countries often put in long hours at work. Any possible gains in cost efficiency may be less likely to stem from technical efficiency gains where one spurs the medical personnel to work even harder under existing stressful conditions. Second, unlike most industries, the health-care sector experiences the unique constraints of input and demand uncertainties (as discussed in the next section), which makes determining the types and quantum of inputs for health-care service delivery challenging. Under such circumstances, the possibility of cost efficiency gains through better allocative efficiency is more plausible as there is constant room for improvement when organizations are not operating at optimal allocative efficiency levels. Finally, the relationship between IT and technical efficiency has been widely studied in the literature with a general consensus that IT leads to improved technical efficiency (e.g., Lee and Barua 1999). We see further contribution to the literature by supplementing the current state of knowledge with a complementary perspective of allocative efficiency. Even so, we recognize the *importance of both* technical and allocative effects of HIT and conscientiously modeled for *both* effects in our empirical model as described later. However, we focus our findings, insights and discussion on the allocative effects.

Constraints and Characteristics of the Health-care Industry

As discussed earlier, recent IS and HIT scholars have argued that research in the health-care context needs to explicitly address its distinctive characteristics in order to better analyze the effects of HIT (Chiasson and Davidson 2005; Kohli and Grover 2008; Payton et al. 2011). We consider three distinct features of the health-care IT industry and explicate how they inform our research study.

Input uncertainty

The first distinctive feature is that the health-care industry is the nature of its work and the implications on how health-care IT could be implemented. Workplace studies in the health-care context show that clinical practices tend to be highly specialized (cardiology practice versus family medicine practice) and are specific to time and place (trauma care center practice versus specialist clinic practice) (Davidson and Chiasson 2005; Faraj and Xiao 2006). In many cases such as a geriatric specialist clinic, the team's daily workload is highly uncertain (in terms of volume), has a high level of ambiguity (in terms of cases, diagnoses etc.), and has severe or vital consequences (Berg 1998; Gawande 2002). For example, the geriatric specialist clinic in our study sees geriatric patients with wide-ranging conditions from cough to chronic diabetes. Each patient is unique and may be encountered at different points in his/her medical trajectory (e.g., early stage of diagnosis versus ongoing chronic care). As such, health-care organizations are unlike other industries such as manufacturing in that health-care organization's processes have a high level of input uncertainty that is largely determined by its local population's health conditions. This has significant implication for effective HIT implementations. Specifically, for HIT to be effective, it has to be coupled with process redesign at strategic points in the organizational structure (Devaraj and Kohli 2000). However this is easier said than done since developing such redesigned processes is costly and complex as it needs to be able to integrate key aspects of the technical and organizational systems with the highly stochastic processes (Payton et al. 2011).

Demand Uncertainty

Related to the issue of input uncertainty is the fact that health-care organizations do not have full control over the demand of its services. This is especially salient for geriatric care sector where the global trend of an ageing population has led to demand for geriatric health-care services outstripping its supply

(Lundsgaard 2005). Given the state of geriatric care, as in the developed Commonwealth country where our study is based, we would expect that the available facilities and providers are often utilized near to its maximum level. This is line with Lee and Menon's (2000) study where they found that hospitals within a single US state operated consistently at a high level of technical efficiency over a period of 18 years (i.e. producing with minimum operating slack). This second feature of health-care industry—externally determined levels of high demand—implies that HIT studies need to adopt the appropriate model to analyze the impact of HIT. Lee and Menon's studies (Lee and Menon 2000; Menon et al. 2000) argued that the appropriate behavioral assumption and production model for health-care organizations is the cost minimization model and not the revenue maximization model as assumed in most IT productivity studies. In other words, we should not assume that HIT's role in health-care organizations is similar to other IT that are applied in other contexts where the goal is to enable greater outputs and/or generate greater revenue (Hitt and Brynjolfsson 1996). Instead, HIT studies should focus on how HIT shape and influence the allocation of resources within clinical and non-clinical processes that support the organizational goal of cost reduction.

IT Embeddedness

Third, as implied by several recent work on HIT (Menon et al. 2009; Setia et al. 2011; Singh et al. 2011), another distinctive feature of the health-care IT context is the variety of HIT applications and the different impacts they have on health-care organizations. Beside the general information systems used to support health-care organizations, HIT research has also studied clinical HIT systems such as electronic medical records (EMR) (Davidson and Chiasson 2005; Lapointe and Rivard 2005), computerized physician order entry (Davidson and Chismar 2007), and telemedicine (Cho and Mathiassen 2007; Pare et al. 2007; Singh et al. 2011). Most of these studies were case-based research and one common finding across them was that the different HIT systems' had different impacts depending on how these systems were embedded into the respective health-care processes. This resonated with a recent work by Menon et al. (2009) who found that clinical information systems had positive short-run impacts while administrative information systems had positive impacts only on the long run. Together these studies makes it clear why it is important for health-care IT research to be specific concerning the type of HIT systems that it is studying and theorizing (Orlikowski and Iacono 2001).

Guided by these key characteristics of HIT research context, our study aims to understand the role of HIT in enabling cost efficiency through improved resource reallocation. We believe that this is important as several studies have shown that while HIT may be instrumental to improving technical efficiencies, there are still significant allocative efficiencies associated with HIT investments to be improved (Menon et al. 2000).

Further, not only does understanding the role of HIT in allocation of resources in line with the cost minimization goal of health-care organization, allocative efficiency as a measure of IT impacts better recognizes the synergies between HIT and business process changes. This is because HIT-led business process changes often requires shifting of tasks and resources (Davenport and Short 1990; Yeow 2008); The inherent input and demand uncertainties in the health-care industry present challenges as well as opportunities for health-care organizations to improve their cost efficiency by embedding HIT in their processes to assign more appropriate input mixes to demand stochasticity.

In our study, we chose to focus on specific HIT system – telemedicine system and its impact on a specific health-care process – outpatient geriatric care. HIT research on telemedicine has traditionally been focused on the efficacy and satisfaction of patients and health-care workers with the telemedicine system (Hailey et al. 2004; Pare et al. 2007). These reviews show that telemedicine has been applied to a variety of clinical and specialist settings such as cardiology, dermatology, neurology, ophthalmology, radiology, as well as geriatric care. As a whole, studies of telemedicine systems found that these systems are effective as alternative mode of health-care delivery, especially in the geriatric care context (Hui et al. 2001; Singh et al. 2011).

While some of the studies found that there was some cost savings derived from substituting face-to-face consultations with telemedicine sessions, the overall review found that there is still limited quality data on the overall economic impact of telemedicine (Brignell et al. 2007; Hailey et al. 2004). However, recent work on remote telemonitoring in the home health-care context provides interesting anecdotal evidence on how telemedicine may potentially impact outpatient geriatric care processes through the reallocation of resources. Singh et al.'s (2011) found that a US-based home health-care provider's implementation of telemonitoring system enabled them to improve its efficiency of deploying clinical resources. They accomplished this by integrating the telemonitoring system's real-time patient information with their redesigned nursing scheduling system and processes. Instead of regular scheduled patients visits, the redesigned process and telemonitoring system enabled a dynamic allocation of clinical resources to patients who do require in-person assistance.

Consistent with these points, our research explains *how does telemedicine system use impacts outpatient geriatric care process through resource reallocation.*

Methodology

In this section we will outline the methodology that is applied to measure the change in resource allocations as hypothesized in our study for a hospital's outpatient geriatric care after the implementation and use of telemedicine system.

Research context

The context of our study is a publicly-funded hospital (referred to as "Karehealth" going forward) that serves the medical needs of the local community located in the northern region within a developed Commonwealth country. Karehealth is an acute-care hospital with a staff strength of 2,650 and operates 476 beds (Karehealth annual report 2011). The geriatric medicine department caters to elderly patients aged 65 and above. In addition to taking care of two specialized inpatient wards in Karehealth, the geriatric medicine department also runs a specialist outpatient clinic.

Karehealth has implemented telemedicine for its geriatric patients on January, 2010 with the aim of better managing costs. This technology is mainly used to support geriatric patients who reside in nursing homes within its health cluster. These nursing homes are not collocated with Karehealth. Prior to the implementation of telemedicine, whenever a nursing home geriatric patient develops a medical condition and requires diagnosis, the nursing home would have to arrange transportation for these patients to Karehealth's geriatric specialist outpatient clinic (or "specialist clinic" for short) at the hospital. Due to Karehealth's internal standard operating procedures, these nursing home patients are generally consulted by a senior consultant[1]. At times when the patient is bed-ridden, the senior consultant will have to personally go to the nursing homes for such medical consultation sessions. In instances where the patient's condition is deemed to be not as severe or if it is a chronic condition, subsequent visits to the specialist clinic maybe be re-allocated to a consultant or a registrar within the geriatric department. Anecdotally, the face-to-face consultation process is more time and cost intensive as it requires the physician to be physically co-located with the patient either in the clinic or at the nursing home thereby reducing flexibility in the scheduling for the physicians' roster (Hui et al. 2001). Additionally, the geriatric specialist clinic will require a senior physician to be continuously present in its premises to handle new cases whenever these cases present themselves.

The goal of Karehealth's telemedicine program was to "improve the matching of resources to patients' needs thus leading to greater efficiency and reduced cost for the health-care system" (Karehealth Telemedicine Report). The first change that telemedicine enabled was that the senior physicians in Karehealth had the flexibility to consult patients without physically going to the nursing home to provide consultations. Karehealth's operational managers and the senior consultants in the geriatric department decided to install the telemedicine system (it is a video-conference system linked by broadband internet connections) at the nursing homes and at the geriatric specialist clinic. Next, they instituted the telemedicine protocol (i.e., process) that enabled teleconsultations between nursing home patients and

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[1] Physicians are classified into various occupational grades under UK and Commonwealth standards depending on their level of experience and expertise. Senior consultants are regarded as the most senior physicians followed by consultants (similar to attending physicians in US) and registrars which are physicians training to be specialized in particular field (similar to residents in US). Naturally, there is an ordinal variation in wage levels depending on the classification.

the geriatric specialist clinic. Upon completion of the teleconsultation, the geriatric specialist would provide the consultation notes and assessment for the nursing homes to follow up. They would also schedule follow-up referrals to the specialist clinic depending on the patient's condition.

To quantify the cost benefits of any possible change in resource allocation with the new telemedicine-enabled process, we collected granular operational level cost and input quantities data from Karehealth's geriatric specialist clinic from 01 October 2009 (3 months prior to the implementation of telemedicine or "pre-telemedicine") to 31 August 2010 (duration of 8 months leading from the use of telemedicine or "post-telemedicine implementation"). In the pre-telemedicine phase, we collected daily data of the total number of patients consulted within the geriatric specialist clinic, the type of physician performing the consultation, the duration of each consultation, the type of patient consulted, and other costs incurred by the consultation task. In the post-telemedicine implementation phase, in addition to the typical clinic consultations, we added daily data of the telemedicine consultation i.e., number of consultations, type of physician, duration, type of patient and other costs. Through this data collection exercise, we are able to map all the internal costs required to service the entire day's patient load for the clinic. Table 1 below provides the descriptive statistics of some of the data collected.

Table 1: Summary Statistics of Daily Patient Load and Inputs

	Before Telemedicine			After Telemedicine		
	Obs	**Average**	**Std. Dev.**	**Obs**	**Average**	**Std. Dev.**
Number of patients	92	14.718	12.654	243	16.834	14.764
Senior Consultant (Time in hours)	92	3.763	3.574	243	4.262	3.92
Consultant (Time in hours)	92	0.774	1.529	243	1.126	1.763
Registrar (Time in hours)	92	0.607	0.824	243	0.658	0.916

Note: The average wages for different physician types is not reported here due to confidentiality issues.

Notably, Karehealth's telemedicine implementation project is well suited to study the impacts of HIT on resource allocations in the health-care processes as it represents a natural, field intervention study whereby we are able to collect granular cost data before and after the use of a clinical IT system. This allows us to compare possible changes of cost and resource use between pre and post technology use.

Research Model

As discussed above, we focus our modeling efforts on public community hospitals, such as Karehealth, from a cost-minimization perspective (Menon et al. 2000; Scott et al. 2000). Community hospitals in this developed Commonwealth country, as in many other similar hospitals (e.g., Bloomfield et al. 1992 in UK; and Kohli and Kettinger 2004 in US), receive significant proportions of their budget from government bodies (e.g. health ministry) and have to operate within the budgetary constraints set by various government agencies. As such, they are more likely to adopt telemedicine to reduce the cost of their operations.

In the process of delivering geriatric health-care services, a significant amount of the cost incurred can be attributed to physicians' wages. Here, we model geriatric specialist consultation process on a daily basis and the unit of analysis for the dependent variable is the number of outpatient consultation sessions in the geriatric clinic for any particular day denoted by the output variable, y. On a daily basis, the variable cost inputs required for the outpatient consultation sessions is the physician's time, denoted by, x and the price level for this input is denoted by the per hour wage level of the physician, denoted by w. As described earlier, each new consultation process requires a physician with varying levels of experience (and wage level). The function of a consultant process can be represented as follows:

$$\ln y = \beta_0 + \sum_n \beta_n \ln x_n + v \qquad \forall\, n = 1, \dots, N \qquad (1)$$

where n represents the occupational grade of physician (senior consultant, consultant or registrar) and v represents stochasticity. β is the output elasticity and here it represents the efficacy of the physician, whereby a higher β means that the physician is able to complete more consultation task per unit time. In this function, we omit other costs that are fixed (invariant) on a daily basis such as overhead costs, costs of counter staff, and nurses which are assigned to the clinic and do not change for all production level instances (i.e. nurses or counter staff do not get re-assigned out of the clinics in days of low patient load). The assignment of physician types to each consultation however varies daily, resulting in a varied cost structure for the clinic across different production instances. Optimally, it will be most cost efficient to assign the appropriate physician (resource) to the patient (task) depending on the complexity of the aliment.

In any production process, there is always a component of technical inefficiency whereby the inputs are not operating at the maximum level due to operational slack. For example, a physician may take a longer duration to consult a patient in order to reduce job fatigue. For a same quantum of input resources, technical inefficiency results in lower output. Hence, equation (1) can be rewritten into:

$$\ln y = \beta_0 + \sum_n \beta_n \ln x_n + v - u \qquad \forall n = 1, \ldots, N;\ u \geq 0 \qquad (2)$$

where u represents the output oriented technical inefficiency in the production. In the case of Karehealth, to minimize cost, $E = \sum_n w_n x_n$ of producing a particular level of patients consulted (output), the first-order condition for the cost minimization problem can be expressed as the system of questions represented by equation (2) with (N-1) first-order conditions shown below (Kumbhakar and Lovell 2000):

$$\ln\left(\frac{x_1}{x_n}\right) = \ln\left(\frac{\beta_1 w_n}{\beta_n w_1}\right) \qquad \forall n = 2, \ldots, N \qquad (3)$$

As shown in Kumbhakar and Lovell (2000), the input allocative efficiency can be represented by η_η as shown in (4) below.

$$\ln\left(\frac{x_1}{x_n}\right) = \ln\left(\frac{\beta_1 w_n}{\beta_n w_1}\right) + \eta_n \qquad \forall n = 2, \ldots, N \qquad (4)$$

where η_n represents input allocative efficiency for the input pair x_1 and x_n. η_n can be positive, zero or negative, which suggests that the input n is over, appropriately or under-utilized (from a cost efficiency perspective) relative to input x_1. For example, if input allocative efficiency for the input pair of consultant and registrar is over-utilized, it means that for the same level of patient consultation output for the day, cost efficiency for the tasks can be improved by relocating more tasks from the registrars to the consultants.

Following Kumbhakar and Lovell (2000), we adopted stochastic frontier analysis (SFA) to solve for the empirical model denoted by equations (2) and (3). We use a maximum likelihood estimator (MLE) to solve for equation (2) simultaneously with N-1 conditions as shown in equation (3) as constraints with u following a half-normal distribution. SFA is a well-established technique to measure the level of technical inefficiencies in production process. Unlike classical data-envelopment techniques (DEA), which is used to solve for technical inefficiencies, SFA estimates production models after accounting for random errors in the estimation process (denoted by v). The SFA estimator charts out the maximum level of output y that can be produced with the inputs x, after considering stochasticity in the process as well as the possibility of individual inputs not producing to the maximum due to operational slack. The estimators are subsequently substituted into equation (4) to obtain the daily input allocative efficiency scores, η_n , for all input pairs (consultant-registrar pair; senior consultant-consultant pair and senior consultant-registrar pair). These scores allow us to assess for any pair of physician inputs, if one type of physician is over (or under) utilized with respect to the other type of physician from a cost efficiency perspective.

To test whether the use of telemedicine changes the way the clinics allocate the type of physician to consultation tasks, we separate the estimation for data before the telemedicine implementation (prior to January 2010) and after telemedicine implementation (on and after January 2010). We subsequently compared the possible changes in allocative efficiency scores, η_n after the implementation.

Results and Findings

The results of the stochastic frontier analysis are presented in Tables 2 and 3 below. Using the estimated coefficients of the stochastic frontier analysis, we estimated the technical inefficiency, u to be 0. 869 (std. dev = 0.041) in pre-telemedicine use and 0. 998 (std. dev. = 2.73 E-6) in post-telemedicine implementation use. This suggests that the physicians are working pretty close to their personal capacity on a daily basis when consulting patients in both pre and post telemedicine use. More importantly, we found that with telemedicine, physicians are working very much near to their technical capacity. This finding is in line with our earlier argument that physicians in most of the outpatient care process are likely working close to capacity (Lee and Menon 2000), and any gains in productivity due to the use of IT is less expected to be in the form of an increased in technical efficiencies (i.e. physicians working harder) but more in the form of increased allocative efficiency (i.e. working smarter in getting the right physician for the job). The additional estimate "log std. dev. of *u*" represents the dispersion of the technical inefficiency over all days. Here, we observed that it is not significantly different from zero for post telemedicine use, suggesting that after the use of telemedicine, we expect the physicians to be working almost close to full technical efficiency.

From Tables 2 and 3, we observed that all inputs (time for all physician types) have a significant and positive impact on the total output produced. Interestingly, we observe that coefficients increase in tandem with the seniority of the physician, which suggests that a senior physician is able to consult more patients per unit time compared to his/her junior counterpart. This is in line with observational evidence, where all else constant, we expect more experienced physicians to be able to arrive at a diagnosis faster than a less experienced one, thereby consuming less input resources – physician's time. Notably, this result is consistent across both pre and post telemedicine implementation.

Table 2: Stochastic Frontier Estimation (Pre-Telemedicine Implementation)

Dependent Var. = Total sessions of medical consultations (daily)	
Independent Variables	**Coefficients (Std. Error)**
Time (senior consultant)	0.382 *** (0.011)
Time (consultant)	0.081 *** (0.011)
Time (registrar)	0.074 *** (0.011)
Constant	2.852 *** (0.097)
Additional estimates	
Log std. dev of v	-2.851 *** (0.304)
Log std. dev of u	-3.373 ** (1.276)

Note: *** *p*-value<0.001; ** *p*-value<0.01

Table 3: Stochastic Frontier Estimation (Post-telemedicine implementation Implementation)

Dependent Var. = Total sessions of medical consultations (daily – telemedicine and in-person)	
Independent Variables	**Coefficients (Std. Error)**
Time (senior consultant)	0.387 *** (0.008)
Time (consultant)	0.073 *** (0.007)
Time (registrar)	0.069 *** (0.008)
Constant	2.693 *** (0.431)
Additional estimates	
Log std. dev of *v*	-2.519 *** (0.091)
Log std. dev of *u*	-13.058 (737.606)

Note: *** *p*-value<0.001

Although we are able to establish that a more senior physician is able to cover more consultation tasks within a shorter time, it does not directly suggest that one should utilize more senior physicians to perform the tasks from a cost efficiency perspective; after all, wages of senior physicians are higher (higher inputs prices). To quantify the right mix of input resources to the outpatient consultation task, we computed the allocative efficiencies (η_n) for each physician type pairs as shown in Table 4 below for both pre and post telemedicine use. The η_n for each input pair measures the extent of which the resource type is over or under utilized after considering the cost (wage) as well as the input's ability to generate output (i.e. efficacy in consulting patients). In Table 4, we observe that the allocative efficiency for the senior consultant – consultant pair decreases significantly (p-value < 0.01) from 1.933 to 0.772 after the use of telemedicine. As described earlier, positive allocative efficiency scores represent input over-utilization. This suggests after telemedicine implementation, there is a re-allocation of consultation from consultants to senior consultants. Prior to the use of telemedicine, consultants are over-utilized (from a cost efficiency perspective) compared to senior consultants. After telemedicine, the clinic experienced cost efficiency savings due to the reassignment of tasks from the consultants to the senior consultants. Our result might sound counterintuitive whereby re-assignment of consultation tasks from a less costly input (consultant) to a more costly input (senior consultant) results in greater cost efficiency. This is however plausible, if we consider that the more costly input (senior consultant) is able to complete the task with a significant shorter amount of time as shown by the coefficients in Table 2 and 3, thereby consuming less resource and achieving greater cost efficiency.

The second result we found from the analysis is that there is a reassignment of tasks from consultants to the more junior registrars (η_n increases from -0.232 to 0.803 after the use of telemedicine; significant p-value <0.01). First, the original negative allocative efficiency score suggests that registrars are underutilized compared to consultants prior to the use of telemedicine. Next, the increase in score after telemedicine suggests that there is a shift in the allocation of tasks from one resource type (consultant) to the other (registrar). More importantly, this increase in the allocative efficiency scores also suggests that the registrars are now over-utilized from a cost efficiency perspective as the result of the tasks reallocation. Registrars have lower wages and correspondingly lower performance efficacy compared to consultants as suggested by their lower β coefficients in Table 2 and 3. The re-assignment of (possibly complex) consultations from consultants to registrars will result in more time being spent in consultation. The use of a less effective resource (though at a lower per unit cost) thereby experiences a decline in cost efficiency due to increase use of the lower cost resource.

Table 4: Computation of the Allocative Efficiencies, η_n

Input Pairs	η_n Pre-Telemedicine (Std. Error)	η_n Post-telemedicine implementation (Std. Error)	t-test (p-value)
Senior Consultant – Consultant	1.933 (0.355)	0.772 (0.198)	2.977 ** (0.003)
Consultant – Registrar	-0.232 (0.378)	0.803 (0.262)	-2.131 ** (0.034)
Senior Consultant – Registrar	1.749 (0.315)	1.575 (0.194)	0.468 (0.640)

Note: ** p-value<0.01; * p-value<0.05

For the final resource pair (senior consultant – registrar), we observed that the registrars are consistently over-utilized compared to senior consultants in both pre and post use of telemedicine (η_η 1.749 in pre and 1.575 in post). Interestingly, the allocative efficiency scores did not change significantly after the use of telemedicine. This finding suggests that there is limited reassignment of tasks between the senior consultants and registrars. Such a finding corroborates with medical practices as consultation tasks that are regarded as complex, hence requiring the time of senior consultants, are unlikely to be assigned to registrars. Similarly, this also suggests that although the use of IT allows the reassignment of resources to tasks to achieve higher cost efficiency, the extent of reassignment can be limited by the inherent difference between the resource types (the skill set differences between senior consultants and registrars are significantly large). Highly effective (and possibly costly) resources might not always be substitutable with less effective (and possibly less costly) resource due to challenges in completing the tasks.

Interestingly, from the allocative efficiencies scores, we can conclude that, during pre-telemedicine use, the clinic has been over-utilizing lower-cost resources (i.e. lower rank physicians) which may appear to help manage cost if one considers only price levels without being cognizant about the effectiveness of each physician type. Although after the use of telemedicine, we observe assignment of physician types to tasks, the level of over-utilization of lower cost resources remains.

Figure 1 below summarizes the key findings of our study. Broadly, we found that the use of telemedicine is associated with shifts in resource allocation to the organizational tasks. Karehealth's geriatric telemedicine consultations of nursing home patients enabled the geriatric specialist to screen nursing home patients who required referrals to Karehealth's geriatric specialist clinics. This screening process via telemedicine resulted in the following shifts in task-resource: consultation sessions that were previously managed by consultants were either reassigned to the senior consultants or to registrars each with differing levels of cost efficiencies due to differences in resource wage levels and efficacies.

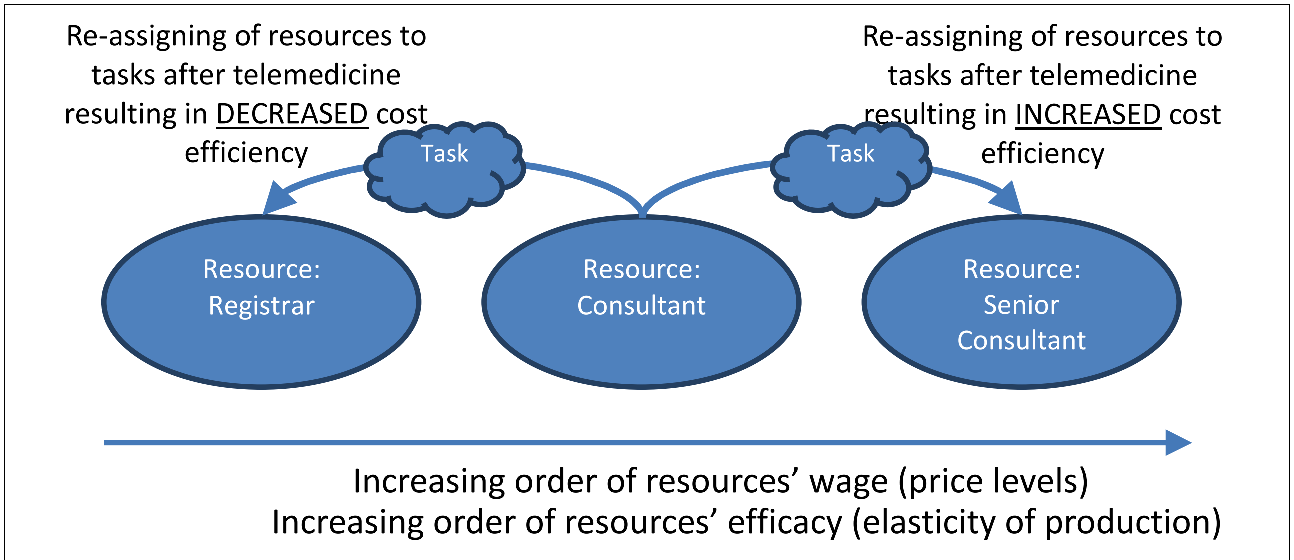

Figure 1. Pattern of resource reassignment through telemedicine

Discussion

The goal of this study is to find out how the implementation of telemedicine system would impact the geriatric care process through the reassignment of resources to tasks. As we have discussed earlier, this approach and focus is important given the distinct characteristics of the health-care context. Specifically in this longitudinal field study of telemedicine-enabled geriatric care, we observed an interesting reassignment of resources to tasks when the telemedicine system is embedded into the geriatric specialist clinic processes. In the pre-telemedicine period, consultants in the geriatric specialist clinic bore the majority of the consultations. After the implementation of telemedicine protocol for nursing home geriatric patients, there was a shift of the specialist clinic consultations from the consultant to the registrars and senior consultants. It is important to note that this reassignment of resources might not always lead to an improvement in cost efficiency. There are times where cost efficiency is increased and in other instances where it decreases. However, the objective of this study is not to simply focus on the cost efficiency gains stemming from the use of telemedicine, but to highlight the possible shifts in resource-task assignment after telemedicine is embedded into the geriatric care processes. More importantly, this study highlights the importance of maintaining a holistic view of measuring cost efficiency in health-care industry where one should balance the cost level of resources and the efficacy of resources for the health-care task when reassigning resources to tasks after introducing new IT systems.

The need to balance between resource price levels and resource efficacy when building new IT-enabled processes is important because an organization's quest to contain costs with the use of IT often leads to the reassignment of tasks to lower priced resources. For example, research on outsourcing and offshoring has shown that the use of inter-organizational IT systems facilitates the opportunities of outsourcing of processes to lower cost venues (Levina and Ross 2003). Although the lowering of per unit costs of the resources is highly relevant to strategic organizational goals, the overall impact of cost efficiency has to be measured from a more holistic view, which takes into account the resources' ability to convert tangible output. Even though our study found that the implementation of new IT-enabled processes provides the opportunities for organization to shape their resource task allocation within its processes, it is important to debunk the misconception that shifting tasks to lower cost resources is the way to go in managing cost within an organization. Related to this issue of process efficiency, as exhibited in this study, the use of information technology to spur cost efficiency through increased technical efficiency (e.g. making physician's work harder), might not be a viable option in instances of working conditions where the production environment is close to being technically efficient. A more holistic approach would be to examine the underlying work tasks, reassigning the appropriate resource with the affordance of information technology to the right set of work routines, thereby working smarter and not harder. Thus, one practical implication of our study is that health-care and HIT management needs to think of HIT not only as a tool to automate and accelerate processes but also as part of strategic process change that relooks at *what* tasks to reassign to *who* and to what extent should we effect this change.

Finally, our study adds to current theoretical work on how HIT, or IT general, impact work processes and organizational performance. Some of the early ideas of how IT may impact work were mainly rooted on the substitution effect of IT as an input in the production function (Bresnahan et al. 2002). Other studies argue that rather than simply a substitute input, IT may also act as a complement to other process changes and inputs to improve firm performance (Devaraj and Kohli 2000; Tanriverdi 2006). Whilst these are important insights, scholars have argued that we need to broaden our repertoire to capture other positive effects of IT (Kohli and Grover 2008). Our study's granular operational data and field study design enabled us to show that in addition to the substitution and complementary effects of IT, IT can potentially play an important role in reallocating costs. Furthermore, we argue that this may be an especially salient measure of HIT given the uniqueness of health-care industry. Future studies could look at how HIT's allocative effects may come into play across multiple health-care organizations who are actively involved in collaborative processes e.g., acute-care hospital, step-down care hospitals and nursing homes.

Limitations

Our study is not without limitations. First, the context of our study is a publicly-funded acute-care hospital that has a predominant focus on managing costs and not maximizing profits. Henceforth, our empirical model is based on cost minimization rather than revenue maximization, which might not be reflective in the case of private, for-profit medical institutions. However, it is important to note that public hospitals still constitute a significant part of the health-care industry and cost minimization principles may still be applied to private hospitals to boost overall net profits.

In our model, we measure the number of patients consulted as the output. One limitation is the lack of quality indicators in the output measure. While we recognize the importance of quality in the health-care setting, we were unable to collect the data in this study due to privacy concerns i.e., we were not allowed to be in contact with the patients to obtain patient-level sentiments about subjective quality. However, subsequent interviews with the geriatric department personnel suggest no significant change in health-care quality within the hospital – an important performance indicator for hospitals in general.

Finally, for the measurement of technical inefficiency, the metric is always limited by the size and scope of study sample. Ideally, a larger sample with multiple hospital sites would provide greater confidence and possibly more insights to the results. Nevertheless, the number of observations we obtained from the 11-month long data collection is sufficient to arrive at statistically robust conclusions.

Conclusion

Whilst the general positive relationship between HIT on hospital performances has become relatively established, there are still significant challenges in identifying the ways by which different HIT could transform complex health-care processes to bring about positive process changes. In this longitudinal field study of telemedicine-enabled geriatric care, we found that HIT impacts are driven by allocative effects. The presence of IT provides opportunities for the organization to reassign non-IT based resources in its clinical work processes with the objective of better matching the uncertainty in medical inputs as well as health-care demands. We also observed that not all reassignment of resources to work tasks lead to greater cost efficiency as there may be inherent limitations in the resources characteristics which can limit one's ability to reassign them to other tasks. From our findings, we further argue that through surfacing the allocative effect of HIT, researchers and managers should be sensitized to the importance of balancing the cost level and the efficacy of resources for the health-care task when reassigning resources to tasks. Given the challenging working conditions in health-care organizations, this study highlights the potential benefits of appropriate resource reassignment, whereby these organizations can strive to achieve greater cost efficiencies through working smarter instead of harder.

References

Amarasingham, R., Plantinga, L., Diener-West, M., Gaskin, D.J., and Powe, N.R. 2009. "Clinical Information Technologies and Inpatient Outcomes: A Multiple Hospital Study," *Archives of Internal Medicine* (169:2), pp. 108-114.

Berg, M. 1998. "Medical Work and the Computer-Based Patient Record: A Sociological Perspective," *Methods of information in medicine* (37:3), Sep, pp. 294-301.

Bloomfield, B.P., Coombs, R., Cooper, D.J., and Rea, D. 1992. "Machines and Manoeuvres: Responsibility Accounting and Construction of Hospital Information Systems," *Accounting, Management, & Information Technology* (2:4), pp. 197-219.

Bresnahan, T.F., Brynjolfsson, E., and Hitt, L.M. 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence," *Quarterly Journal of Economics* (117:1), pp. 339-376.

Brignell, M., Wootton, R., and Gray, L. 2007. "The Application of Telemedicine to Geriatric Medicine," *Age and Ageing* (36), pp. 369-374.

Chiasson, M., and Davidson. 2005. "Taking Industry Seriously in Information Systems Research," *MIS Quarterly*), Jan 1.

Cho, S., and Mathiassen, L. 2007. "The Role of Industry Infrastructure in Telehealth Innovations: A Multilevel Analysis of a Telestroke Program," *European Journal of Information Systems* (16:6), Jan 1, pp. 738-750.

Davenport, T., and Short, J. 1990. "The New Industrial Engineering: Information Technology and Business Process Redesign," *Sloan Management Review* (Summer), pp. 11-27.

Davidson, E.J., and Chiasson, M. 2005. "Contextual Influences on Technology Use Mediation: A Comparative Analysis of Electronic Medical Record Systems," *European Journal of Information Systems* (14), Jan 1, pp. 6-18.

Davidson, E.J., and Chismar, W.G. 2007. "The Interaction of Institutionally Triggered and Technology-Triggered Social Structure Change: An Investigation of Computerized Physician Order Entry," *MIS Quarterly* (31:4), pp. 739-758.

Devaraj, S., and Kohli, R. 2000. "Information Technology Payoff in the Health-Care Industry: A Longitudinal Study," *Journal of Management Information Systems* (16:4), pp. 41-67.

Devaraj, S., and Kohli, R. 2003. "Performance Impacts of Information Technology: Is Actual Usage the Missing Link?," *Management Science* (49:3), pp. 273-289.

Dewan, S., and Min, C.-k. 1997. "The Substitution of Information Technology for Other Factors of Production: A Firm Level Analysis," *Management Science* (43:12), pp. 1660-1675.

Faraj, S., and Xiao, Y. 2006. "Coordination in Fast-Response Organizations," *Management Science* (52:8), Aug 24, pp. 1155-1169.

Fichman, R.G., Kohli, R., and Krishnan, R. 2011. "The Role of Information Systems in Healthcare: Current Research and Future Trends," *Information Systems Research* (22:3), pp. 419-428.

Gawande, A. 2002. *Complications: A Surgeon's Notes on an Imperfect Science*. New York: Picador.

Hailey, D., Ohinmaa, A., and Roine, R. 2004. "Study Quality and Evidence of Benefit in Recent Assessments of Telemedicine," *Journal of Telemedicine and Telecare* (10), pp. 318-324.
HIMSS. 2012. "Eight-Country Survey Finds Doctors Agree on Top Healthcare It Benefits," in: *HIMSS Newsletter*. HIMSS.
Hitt, L.M., and Brynjolfsson, E. 1996. "Productivity, Business Profitability, and Consumer Surplus: Three Different Measures of Information Technology Value," *MIS Quarterly* (20:2), pp. 121-142.
Hui, E., Woo, J., Hjelm, M., Zhang, Y.T., and Tsui, H.T. 2001. "Telemedicine: A Pilot Study in Nursing Home Residents," *Gerontology* (47), pp. 82-87.
Institute of Medicine. 2001. *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, D.C.: National Academy Press.
Kohli, R., and Grover, V. 2008. "Business Value of It: An Essay on Expanding Research Directions to Keep up with the Times," *Journal of the Association for Information Systems* (9:2), pp. 23-39.
Kohli, R., and Kettinger, W.J. 2004. "Informating the Clan: Controlling Physicians' Costs and Outcomes," *MIS Quarterly* (28:3), pp. 363-394.
Kumbhakar, S.C., and Lovell, C.A.K. 2000. *Stochastic Frontier Analysis*. Cambridge, UK: Cambridge University Press.
Lapointe, L., and Rivard, S. 2005. "A Multilevel Model of Resistance to Information Technology Implementation," *MIS Quarterly* (29:3), pp. 461-491.
Lee, B., and Barua, A. 1999. "An Integrated Assessment of Productivity and Efficiency Impacts of Information Technology Investments: Old Data, New Analysis and Evidence," *Journal of Productivity Analysis* (12:1), pp. 21-43.
Lee, B., and Menon, N.M. 2000. "Information Technology Value through Different Normative Lenses," *Journal of Management Information Systems* (16:4), pp. 99-119.
Levina, N., and Ross, J.W. 2003. "From the Vendor's Perspective: Exploring the Value Proposition in Information Technology Outsourcing," *MIS Quarterly* (27:3), pp. 331-364.
Lundsgaard, J. 2005. "Consumer Direction and Choice in Long-Term Care for Older Persons, Including Payments for Informal Care: How Can It Help Improve Care Outcomes, Employment and Fiscal Sustainability?." OECD Health Working Papers.
Menon, N.M., Lee, B., and Eldenburg, L. 2000. "Productivity of Information Systems in the Healthcare Industry," *Information Systems Research* (11:1), pp. 83-92.
Menon, N.M., Yaylacicegi, U., and Cezar, A. 2009. "Differential Effects of the Two Types of Information Systems: A Hospital-Based Study," *Journal of Management Information Systems* (26:1), pp. 297-316.
Orlikowski, W.J., and Iacono, C.S. 2001. "Research Commentary: Desperately Seeking the "It" in It Research—a Call to Theorizing the It Artifact," *Information Systems Research* (12:1), pp. 121-134.
Pare, G., Jaana, M., and Sicotte, C. 2007. "Systematic Review of Home Telemonitoring for Chronic Diseases: The Evidence Base," *Journal of the American Medical Informatics Association* (14:3), pp. 269-277.
Payton, F.C., Pare, G., LeRouge, C., and Reddy, M. 2011. "Health Care It: Process, People, Patients and Interdisciplinary Considerations," *Journal of the Association for Information Systems* (12:2/3), pp. i-xiii.
Scott, W.R., Ruef, M., Mendel, P.J., and Caronna, C.A. 2000. *Institutional Change and Healthcare Organizations*. Chicago, IL: University of Chicago Press.
Setia, P., Setia, M., Krishnan, R., and Sambamurthy, V. 2011. "The Effects of the Assimilation and Use of It Applications on Financial Performance in Healthcare Organizations," *Journal of the Association for Information Systems* (12:2/3), Apr 30, pp. 274-298.
Singh, R., Mathiassen, L., Stachura, M.E., and Astapova, E.V. 2011. "Dynamic Capabilities in Home Health: It-Enabled Transformation of Post-Acute Care," *Journal of the Association for Information Systems* (12:2), pp. 163-188.
Tanriverdi, H. 2006. "Performance Effects of Information Technology Synergies in Multibusiness Firm," *MIS Quarterly* (30:1), pp. 57-77.
Yeow, A. 2008. "The Work Network Model: Understanding the Interplay of Actor, Artifact, and Action in Technology-Based Change," in: *DOIT*. College Park, MD: University of Maryland, p. 275.