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Efficiency and Technological Change in Health Care Services in Ontario

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Abstract

This paper presents productivity measurement results for hospital services using panel data for Ontario hospitals between 2003 and 2006. The study uses the Malmquist Productivity index (MPI) obtained through the application of Data Envelopment Analysis (DEA) which is decomposed into efficiency change (ECH), i.e., movement towards the best practice frontier and technological change (TCH), i.e., movement of the frontier itself (Färe *et al*. [12]). The study also uses kernel density estimation techniques for analysis of efficiency distributions of the productivity scores and their components across different types of hospitals (e.g. small /large and rural /urban) and over time. Our results suggest that in addition to average productivity it is important to examine distributions of productivity and of its components which we find differs by hospital type and over time. We find that productivity growth occurred mostly through improvement in technology and in spite of declining efficiency. The results provide useful insight into the underlying mechanisms of observed changes in overall productivity, in technological change and in technical efficiency change in this vital sector of the health care market.

Key words: Health Services Sector; Malmquist Productivity Index; DEA; Kernel Density Estimation and Tests; Bootstrapping

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Introduction

The goal of our study is to investigate productivity change in the hospital sector as well as its key components: efficiency change and technological change. To study these questions we use recent advances in productivity analysis—non-parametric (kernel-based) statistical analysis of distributions of productivity scores and their components obtained from the Malmquist Productivity index (MPI) through application of the data envelopment analysis (DEA) estimator.

Many studies have used the MPI to measure efficiency and technological changes of hospital services. The idea of the index originated with Sten Malmquist [38], who used it in the context of consumer theory. It was later reincarnated for use in productivity measurement in the seminal work of Caves *et al.* [5], and further developed in many other studies.[1] One important advantage of the MPI method is that it can accommodate a multi-output-multi-input set up, even when there is only quantity information available, requiring neither relative price information nor restrictive behavioural assumptions in its estimation. Following Färe *et al.* [12] the MPI application allows for estimation of changes in overall productivity and then for decomposition into efficiency changes (ECH) and technological changes (TCH) for each decision making unit (DMU) over time.

For the estimation of MPI and its components, we use DEA, which is a non-parametric estimator, imposing neither functional form for technology nor distributional assumptions about variables or error terms. DEA is widely used to estimate the MPI and technical efficiency in complex production environments with multiple inputs and multiple outputs[2] and in application to

[1] E.g., see Färe *et al.* ([12], [13], [14]), Thrall [62], Førsund [17], Grifell-Tatjé and Lovell ([22], [23]), Kumar and Russell [32] and Henderson and Zelenyuk [28], to mention just a few.
[2] E.g., see Emrouznejad *et al.* [9], Gattoufi *et al.* [18], [19], [20]), Seiford [58].

health care in particular.[3] Most of the literature has tended to be concerned with analysis of unconditional or conditional means (e.g., regressions) or variances. One of the novelties of our work is that we analyse distributions of productivity scores, comparing them over time and across different types of hospitals utilizing the bootstrap-based Li [34] test, adapted to DEA by Simar and Zelenyuk [60]. We observe significant and persistent inefficiencies in the delivery of health care services in the Ontario hospital data. We find that over time rural hospitals experienced higher technical efficiency compared to their urban counterparts, however, at the cost of higher lengths of stay. Though at one point small hospitals achieved higher technological progress, over the time period they encountered increasing technological regress and deterioration in technical efficiency. This coincided with a period in which policy makers were focusing investments in medical technologies in larger hospitals focusing a centre of excellence.

The results of our study can assist decision-makers to understand inefficiencies across different types of hospitals as well as inform the resource allocation process by highlighting potential sources of inefficiency amenable to policy intervention. The results can also help to target efficient allocation of resources and to identify specific areas of efficiency that need improvement.

This study is organised as follows. Section 1 provides a brief review of the literature to provide context for the current study. Section 2 outlines the methodology, Section 3 discusses the data, and Section 4 highlights the estimation results. Section 5 discusses the implications of the efficiency distribution analysis and Section 6 concludes.

1. Brief Overview of Efficiency and Productivity in Healthcare Services

Many studies have used the Malmquist productivity index to measure efficiency and technological change of hospital services. Using an input-based MPI, Sommersgutter-Reichmann [61] studied changes in productivity in the provision of hospital care in Austria between 1994 and

[3] E.g., see O'Neill *et al.* [47], Grosskopf *et al.* ([26], [27]), Ferrier and Valdmanis [16], Hollingsworth ([29], [30]), Mobley and Magnussen [42], Wang *et al.* [63], O' Neill [46] Ozcan [49], Chirikos and Sear [6], etc.

1998. The author found a considerable positive shift in hospital technology between 1996 and 1998 with no enhancement in technical efficiency due to the introduction of an activity-based hospital financing system. Ozcan and Luke [50] found that productivity improved considerably in veteran integrated service networks, primarily because of technological change (i.e., shifts in the frontier) rather than efficiency changes (i.e., movement toward the frontier). Burgess and Wilson [4] examined U.S. hospitals from 1985-1988 and found that changes in technology dominated changes in inefficiency in determining changes in productivity. McCallion *et al.* [41] studied hospitals in Northern Ireland from 1986 to 1992 and found that technological increase was outweighed by a decline in efficiency for small hospitals and that scale efficiency declined. Sahin *et al.* [53] noted that technological progress was the main driver of the improved productivity in 2007 due to Ministry of Health (MoH) investments in general Hospitals, but that there was a decrease in technological progress the following year which left overall productivity unchanged.

Ferrier and Valdmanis [16] studied the efficiency and productivity changes in large urban hospitals in the United States and found that during the 1994-2002 period hospitals made modest gains in their economic performance by both improving their technical efficiency and by adopting more productive technologies. In a study based on 75 Scottish acute hospitals from 1991/92 to 1995/1996, Maniadakis *et al.* [39], noted that productivity changes are dominated by technological change with a little change in hospital efficiency. Färe *et al.* [13] investigated 17 Swedish hospitals and found a wide variation in performance during the period 1970-1985. They found that long-term average annual productivity growth was negative for 13 out of 17 hospitals. They concluded that thirteen out of 17 hospitals experienced annual technological regress and only 5 out of 17 exhibited average annual gains in efficiency. A similar finding was found by Ozgen and Ozcan [51] showing improvement in technical efficiency along with a regress in technologies causing major source of negative movement in productivity. Efficiency gains were found following changes in hospital financing for several other countries including Spain (Gonzalez and Barber, [21]) and Norway (Biorn *et al.,* [3]).

Applying the MPI, Luoma and Järviö [37] found that productivity gains occurred in Finish Health Centers from 1988-95 at the same time as the state and municipalities experienced severe financial difficulties due to a severe recession and falling tax revenues. However, investigating the impact of a subsidy reform in 1993 on the efficiency of the Finnish hospital sector Linna [35] concluded that the reform did not have a significant impact on observed productivity growth. From a study in Turkey Lobo *et al.,* [36] noted that increased budgets through financing reforms worked as a positive stimulus for improvement in technical efficiency, although the production frontier did not shift outward. Langabeer and Ozcan [33] in their study of cancer care centers noted that despite advances in technology and greater scale, average efficiency experienced a marginal decline.

From the literature we note that productivity changes can occur by either changes in efficiency or changes in technology or changes in both. In some studies technological change was found to be the dominant factor while in other studies it was the change in technical efficiency that contributed more to the change in overall productivity. In some studies both efficiency and technological change equally contributed to the overall productivity change. Productivity changes were mostly dominated by technological advancement and a positive change in technical efficiency has outweighed the impact on overall productivity due to technological regress. The impact of financial reform on change in technical efficiency was shown to have either some positive (in Turkey) or no impact (in Finland) on technical efficiency.

2. Methodology

2.1. Theoretical Framework of the Malmquist Productivity Index (MPI)

To measure productivity change and its components we assume that the technology of producing hospital services can be characterized by the production set S^t which models the transformation of inputs $x^t \in \mathbb{R}_+^N$ into outputs $y^t \in \mathbb{R}_+^M$ at time *t* and is defined as:

$$S^t = \{(x^t, y^t) \in \mathbb{R}_+^N \times \mathbb{R}_+^M \ : \ x^t \ \mathit{can\,produce}\ y^t\}. \tag{1}$$

We assume that hospitals face a fixed quantity of inputs under the global budget and subject to this resource constraint a hospital manager must decide how many patients to treat. This would imply that productivity and efficiency measurement must consider the extent to which outputs can be expanded without altering the quantity of inputs (see Jacobs *et al.* [31], pp 105-106 for more discussion on this issue). An appropriate tool in this case would be Shephard's (1970) output distance function, which for a period t, is defined as

$$D_O^t(x^t, y^t) = \inf_\theta\{\theta > 0 : (x^t, y^t/\theta) \in S^t\} \tag{2}$$

Note that $D_O^t(x^t, y^t) \leq 1$ if and only if $(x^t, y^t) \in S^t$. In addition, $D_O^t(x^t, y^t) = 1$ if and only if (x^t, y^t) is on the (output) isoquant or frontier of technology, which in the terminology of Farrell [15], occurs when production is technically efficient. Now, to define the MPI, we need an intertemporal extension of (2), which is defined as

$$D_O^\tau(x^s, y^s) = \inf_\theta\{\theta > 0 : \ (x^s, y^s/\theta) \in S^\tau\}, \quad \tau, s \in \{t, \ t+1\} \tag{3}$$

When $\tau = s$ we obtain (2), while when $\tau = t, \ s = t+1$ we get the distance function $D_O^t(x^{t+1}, y^{t+1})$ measuring the maximum proportional change in outputs required to bring (x^{t+1}, y^{t+1}) onto the frontier of technology at the previous period t. Similarly, when $\tau = t, \ s = t+1$ we get the distance function $D_O^{t+1}(x^t, y^t)$ measuring the maximum proportional change in output required to bring (x^t, y^t) onto the frontier of technology at $t+1$. Using these intertemporal measures, we follow Caves, et al (1982) to define the output-oriented Malmquist productivity index as

$$M_O(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \tag{4}$$

Furthermore, in the spirit of Nishimizu and Page [44], Färe *et al.* [12, 13] decomposed the MPI into efficiency change (ECH) and technology change (TCH), as

$$M_o\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} = ECH \times TCH. \qquad (5)$$

The efficiency change term (ECH) is equivalent to the ratio of Farrell technical efficiency in period $t + 1$ divided by Farrell technical efficiency in period t. The technological change (TCH) term is the geometric mean of the shift in technology as observed at $\left(x^{t+1}, y^{t+1}\right)$ (the first ratio inside the bracket) and the shift in technology observed at (x^t, y^t) (the second ratio inside the bracket). The ECH component is greater than, equal to, or less than unity depending on whether efficiency of the evaluated DMU improves (catching-up to the frontier effect), stagnates, or declines. Depending on the case, the TCH may also take a value greater than, equal to, or less than unity – so that technological change would be positive, zero, or negative, respectively.

One of the most common ways to estimate the MPI (Färe *et al.* [12]) is based on application of DEA techniques (Charnes *et. al.* [11], Farrell [15]), which, for estimating MPI score of any DMU j ($j = 1, \dots, n$), requires solving four linear programming problems, given by

$$\left(\widehat{D}_o^{\tau}\left(x^{j,s}, y^{j,s}\right)\right)^{-1} = \max_{\theta, z^1 \dots z^n} \{\theta \ : \ \theta \geq 0, \ \sum_{k=1}^{n} z^k y_m^{k,\tau} \geq y_m^{j,s}\theta, \ m = 1, \dots, M,$$

$$\sum_{k=1}^{n} z^k x_i^{k,\tau} \leq x_i^{j,s}, \ i = 1, \dots, N, \ z^k \geq 0, \ k = 1, \dots, n\}, \quad \tau, s \in \{t, \ t+1\} \qquad (6)$$

where $\left(x^{j,s}, y^{j,s}\right)$ is input-output allocation of DMU j observed in period $s \in \{t, \ t+1\}$, for which we want to estimate the value of the distance function relative to the frontier in period $\tau \in \{t, \ t+1\}$; while $\{z^k, \ k = 1, \dots, n\}$ is a set of intensity variables over which we optimize (jointly with optimizing over θ), that serve as weights that help envelope the frontier using the data $\left\{\left\{\left(x^{k,s}, y^{k,s}\right)\right\}_{k=1}^{n}\right\}$ in a given period $\tau \in \{t, \ t+1\}$.

In summary, through application of this approach we can evaluate the extent to which hospitals have moved toward the best practice frontier (ECH) and whether there has been a movement in the frontier itself (TCH) over time.

2.2. Analysis of Distributions of MPI and its Components

In our distributional analysis we use the kernel density estimator (KDE), given by

$$\hat{f}_h(\delta^o) := \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{\delta_i - \delta^o}{h}\right),$$

where h is a bandwidth, K is a kernel function and $\{\delta_i: i = 1, \dots, n\}$ is a random sample of some random variable δ, whose density function, f, we want to estimate at a point δ^o. Our choice of the Gaussian kernel and Sheather and Jones [56] bandwidth selector, ensures that KDE is a consistent estimator of the true density, f, that generated the random sample we used.

Now, suppose we have two random samples $\{\delta_{A,i} : i = 1, \dots, n_A\}$ and $\{\delta_{Z,i} : i = 1, \dots, n_Z\}$ that came from distributions characterized at a point δ by density functions $f_A(\delta)$ and $f_Z(\delta)$, respectively. We want to test whether these distributions are the same, i.e., our hypotheses are

H_0: $f_A(\delta^o) = f_Z(\delta^o)$, $\quad \forall\, \delta^o$ in the support of the random variables δ_j (j = A, Z)

H_1: $f_A(\delta^o) \neq f_Z(\delta^o)$, $\quad$ (on a set of positive measure).

To infer on these hypotheses, we can use the Li [34] test statistic, given by

$$n_A h^{1/2} \widehat{ISD}^0_{n_A n_Z h} \Big/ \sqrt{\hat{\sigma}^2_{\lambda,h}} \;\xrightarrow{d}\; N(0,1), \tag{7}$$

where

$$\widehat{ISD}^0_{n_A n_Z h} = \frac{1}{n_A^2 h}\sum_{\substack{i=1\\ i\neq k}}^{n_A}\sum_{k=1}^{n_A} K\left(\frac{\delta_{A,i}-\delta_{A,k}}{h}\right) + \frac{1}{n_Z^2 h}\sum_{\substack{i=1\\ i\neq k}}^{n_Z}\sum_{k=1}^{n_Z} K\left(\frac{\delta_{Z,i}-\delta_{Z,k}}{h}\right) - \frac{1}{n_A n_Z h}\sum_{\substack{i=1\\ i\neq k}}^{n_A}\sum_{k=1}^{n_Z} K\left(\frac{\delta_{A,i}-\delta_{Z,k}}{h}\right) - \frac{1}{n_Z n_A h}\sum_{\substack{i=1\\ i\neq k}}^{n_Z}\sum_{k=1}^{n_A} K\left(\frac{\delta_{Z,i}-\delta_{A,k}}{h}\right). \tag{8}$$

and

$$\hat{\sigma}^2_{\lambda,h} := 2\left\{\frac{1}{n_A^2 h}\sum_{i=1}^{n_A}\sum_{k=1}^{n_A} K\left(\frac{\delta_{A,i}-\delta_{A,k}}{h}\right) + \frac{\lambda_n^2}{n_Z^2}\sum_{i=1}^{n_Z}\sum_{k=1}^{n_Z} K\left(\frac{\delta_{Z,i}-\delta_{Z,k}}{h}\right) + \frac{\lambda_n}{n_A n_Z h}\sum_{i=1}^{n_A}\sum_{k=1}^{n_Z} K\left(\frac{\delta_{A,i}-\delta_{Z,k}}{h}\right) + \frac{\lambda_n}{n_Z n_A h}\sum_{i=1}^{n_Z}\sum_{k=1}^{n_A} K\left(\frac{\delta_{Z,i}-\delta_{A,k}}{h}\right)\right\} \int K^2(z)dz\,. \tag{9}$$

where $\lambda := \lim_{n\to\infty} \lambda_n$ with $\lambda_n = n_A/n_Z$, $n = n_A + n_Z$ (here we use Silverman's rule-of-thumb for h).

Note that for our context of comparing distributions of productivity scores, $\delta_{j,i}$ stands for the *true* MPI scores or their *true* components for hospital i in a group (or time period) j. The true productivity scores are estimated via DEA. Using estimates in place of true scores to estimate the densities of the *true* scores as well as for performing the Li-test on equality of distributions, creates similar problems as those discussed in detail in Simar and Zelenyuk [60] for the context of efficiency scores obtained from DEA. To deal with this double-estimation problem, we follow Simar and Zelenyuk [60], and adapt their logic to the context of testing equality of distributions of productivity scores from MPI and its components.

3. Data

The empirical study used balanced panel data for 113 acute care hospitals in Ontario over the period 2002/2003 to 2005/2006. All Ontario hospitals are independent, private not-for-profit organizations. However, they receive virtually all funding from the provincial government (global budgets). Data for this study were extracted from Health care indicator tool (HIT), from the Ministry of Health and Long Term Care (MOHLTC) and Canadian Institute for Health Information acute care discharge abstract database (CIHI-DAD). The HIT provides data based on audited financial and statistical reports by hospitals to the MOHLTC. Both sources of data are also subject to data quality audits.

The set of inputs and outputs that we have used in this study are similar to those applied in previous studies on hospital productivity. While reviewing DEA based hospital efficiency studies, O'Neill *et al.*, [47] provided an extensive discussion about the inputs and outputs used in previous studies. Hospital input categories fall into three broad sub-categories namely capital investment, labour, and other operating expenses. The number of fully staffed hospital beds is most often used as a proxy for hospital size and capital investment. The ''number of clinical staff'', consists of physicians, nurses, and other health/medical personnel was used as a proxy for ''labour costs''.

Most studies that did not include clinical staff used labour costs instead. Several studies included the number of non-clinical staff as a hospital input including technical, managerial, and other staff. The range of hospital output categories found in the literature can be classified into four subcategories: (1) medical visits, cases, patients, and surgeries, (2) inpatient days (3) admissions, discharges, and services and (4) other specific output categories (e.g., a typical teaching).

As multi-product decision making units, hospitals in Ontario produce varying quantities of services and obviously none of these services is homogenous. Though heterogeneity and joint production are the prevalent characteristics of the hospital services sector, DEA being a linear programming technique for estimating the frontier, requires that the units of measurement of output are uni-dimensional and are the same across hospitals. On the basis of production theory, it is also assumed that output measures are cardinal measures so that the levels and differences are important and meaningful. Ordinal measures which provide an indication of ranking as opposed to differences in actual levels, should not be used as output measures within DEA (Coelli *et al.*, [7]). Further, Ozgen and Ozcan [51] noted that inclusion of case-mix variables in efficiency analyses may be less necessary as the DEA technique permits the reduction in the case-mix variation by specifying multiple outputs. The most commonly used measure of hospital output is the number of patient days produced as it is considered uni-dimensional and medically homogenous. In keeping with many other studies e.g., Cowing and Holtman [8], Sherman [57], Banker *et al.* [2], Grosskopf and Valdmanis [24], Färe *et al.* [10], Ozgen and Ozcan [51], Sahin *et al.* [53], Ozcan and Luke [50], we have used both inpatient and outpatient volume as a measure of output. The advantage of using service quantity is that it has a direct link between the quantity of health services and the input. This means that the observed output is specific to input. We do however recognize that this is a simplifying assumption, that may not fully reflect the diversity of the underlying patient populations.[4]

We have included all hospitals in Ontario except specialized services such as rehabilitation, mental or psychiatry services. However, not all hospitals in Ontario provide all services e.g., surgical and thus we take an aggregate measure of total output, rather than dis-aggregating output to the department level.

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[4] Some also argued that efficiency scores are sensitive to the use of patient days and therefore recommended using cases rather than inpatient days. See Ozcan [48], Grosskopf and Valmanis [25], Burgess and Wilson [4], Maniadakis [39] for more detail on case mix adjustment in efficiency and productivity measurement.

Three different types of inputs are used: (1) human resources including nurses and administrative workers, (2) purchased services and supplies including medical/surgical supplies and non medical/surgical supplies and finally (3) the number of staffed beds and total equipment expense as measures of capital. Beds and service-mix have also been considered as measures of hospital assets (e.g., see Ozcan [48]).

Table 1. Descriptive Statistics of the variables

Statistics	Year	Y1	Y2	X1	X2	X3	X4	X5	X6
		Number of outpatient visits	Total Number of inpatient days	Staff hours	Nursing hours	Number of Staffed beds	Medical surgical supply cost	Non-medical surgical supply cost	Total Equipment Expense
Mean	2003	103011	61267	52486	677422	67227	4868412	5631091	5107739
	2004	113434	61757	51297	696763	67898	5259491	5783138	5371287
	2005	117607	60715	50545	702730	66665	5866280	6035734	5985967
	2006	119520	61847	50322	717555	66677	6255304	6208020	6408850
Median	2003	38553	23522	19401	219936	26432	592934	1659732	1289592
	2004	40916	23131	20467	218114	29479	664647	1740728	1370568
	2005	47326	22546	20255	213045	28191	877269	1709075	1612962
	2006	47686	22340	20342	212638	25915	924480	1829179	1726518
Std. Dev	2003	142335	78672	70141	955929	82372	8466327	8672777	7679266
	2004	161501	79675	70573	989776	83010	9166301	8864644	8167388
	2005	168079	77933	75620	1003986	81430	10154920	9389034	9235885
	2006	167453	79746	72031	1019862	81676	10715645	9181545	9970961
min	2003	2116	3611	1590	32779	5124	28503	322212	210211
	2004	1943	2827	1943	29261	5013	37729	322294	210710
	2005	2307	3192	2455	29312	2850	28217	354466	289424
	2006	2328	3141	2810	28948	3350	24506	355470	248512
max	2003	785843	399133	403839	4739455	426716	46302098	52362963	38585082
	2004	859203	399130	424701	5030636	435443	49497660	50125529	46442249
	2005	893831	377818	537272	4892130	414236	54863488	54044736	58250123
	2006	901423	380634	479952	5114700	412484	57397601	45073828	64483725

Over the time period, average hospital nursing hours increased (5.9%) while non-nursing staff hours decreased leading to a total decrease of 4.1%. At the same time, inpatient volume increased slightly and outpatient volume increased substantially, reflecting a continuing trend to outpatient procedures and potentially also better hospital management and cost containment strategies. The average staffed beds decreased marginally over the sample period, which may be the result of an effort to reduce costs, increase occupancy rates and also to transfer inpatient cases to the community. Both medical surgical and non-medical surgical supply costs increased over the sample period. Hospitals also increased spending on equipment by more than 25% over the sample period, indicating more investment in medical technologies.

4. Estimation Results: An Overview

With 113 hospitals over the period 2003 to 2006, we do not present all the estimates of individual hospital scores but they are available from the authors on request. Here we provide a summary of the analysis. Descriptive statistics of MPI, ECH and TCH are shown in Table 1A in the Appendix II. Figure 1 depicts the estimated MPI summary of annual means. Over the course of the study period, productivity declined except for the period 2004-2005 when average growth of productivity was only 0.2%. Average efficiency change declined during the periods 2003-2004 and 2005-2006, however, it increased by 2.3% during the period 2004-2005. Periods 2003-2004 and 2004-2005 experienced some technological regress but the period 2005-2006 had more technological progress leading to overall technological progress during the period 2003-2006. However, average productivity did not increase significantly, due to negative efficiency change. In particular, growth in productivity is largely due to a progressive shift in the best practice frontier over the sample period rather than by improvement in the technical efficiency of hospitals. A similar result has been reported in other jurisdictions (e.g., see McCallion *et al.* [41], Burgess and Wilson [4], Sommersgutter-Reichmann [61], Maniadakis *et al.* [39], and Ozcan and Luke [50].

Out of 113 hospitals, 48 hospitals experienced productivity growth in 2003-2004. The corresponding figures for productivity growth for 2004-2005 and 2005-2006 are 55 and 56 respectively. In 2003-2004, 65 hospitals experienced negative productivity growth. The number of hospitals that experienced negative productivity growth during 2004-2005 and 2005-2006 were 58 and 57, respectively. In 2005-2006, 98 hospitals experienced technological progress while a large number of hospitals experienced technological regress in both the 2003-2004 and 2004-2005 periods. Though a large number of hospitals experienced an increase in efficiency in both the 2003-2004 and 2004-2005 periods, only 16 out of 113 hospitals, experienced increased efficiency in 2005-2006.

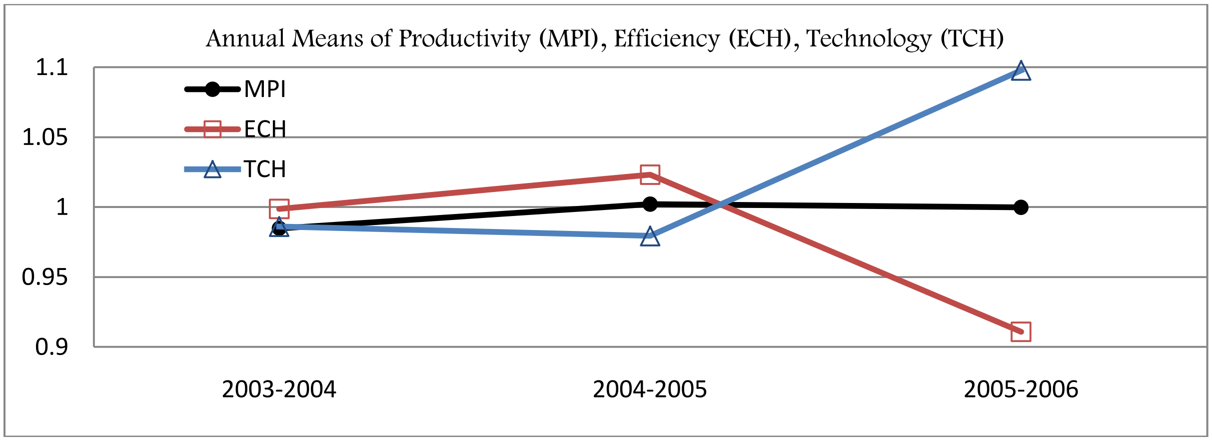

Figure 1

Examining the returns to scale we found that a large number (65%) of hospitals in Ontario operated at the level of decreasing returns to scale and so faced diseconomies of scale (see Figure 2.2). Only about 10% of hospitals operated under increasing returns to scale meaning they were too small and could benefit from expansion.

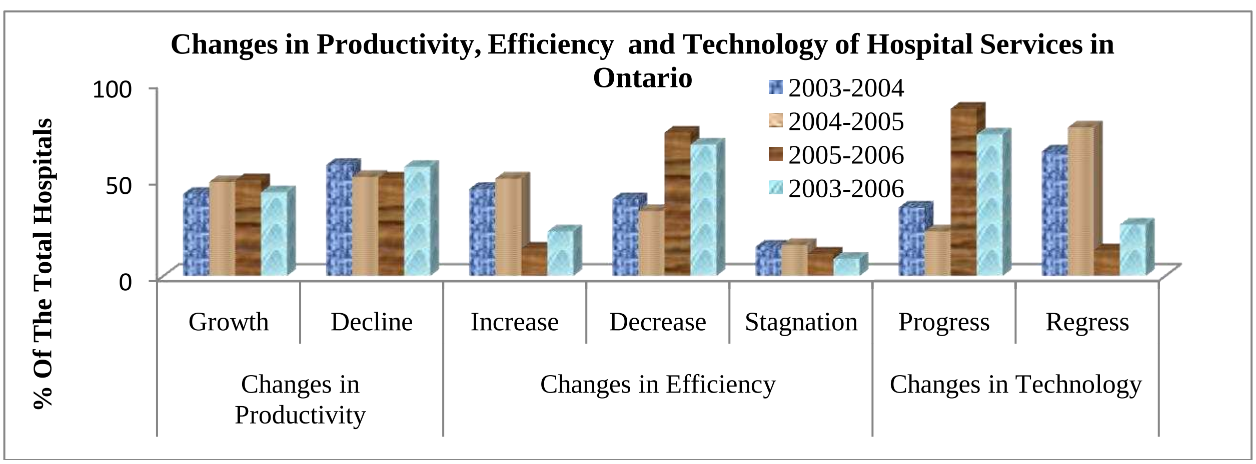

Figure 2.1

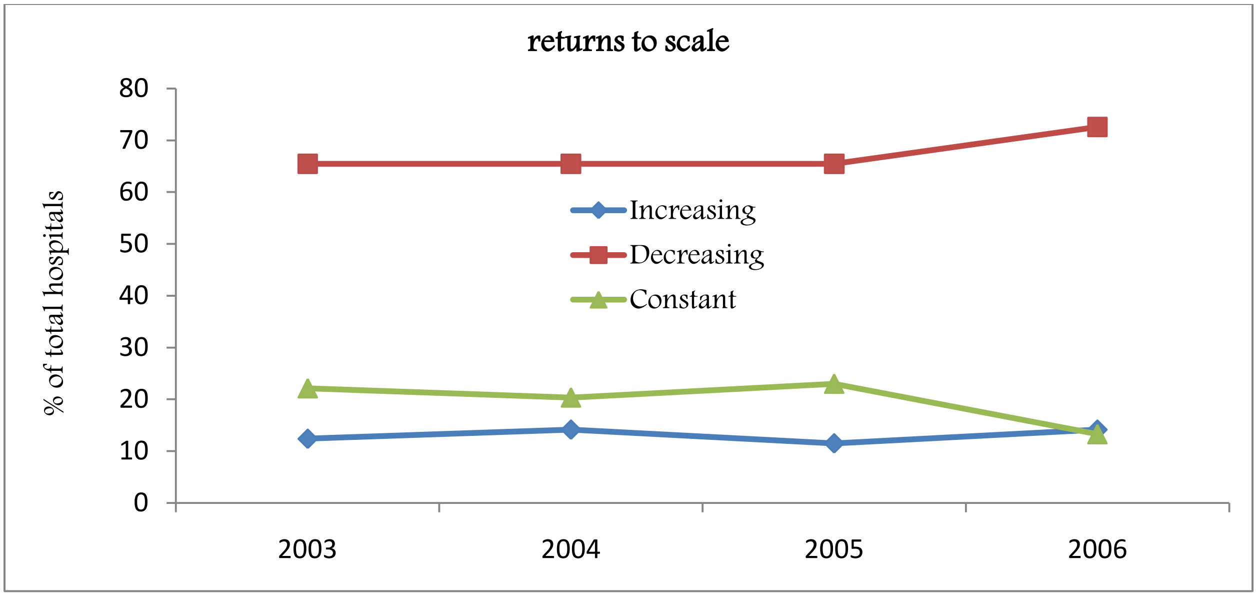

Figure 2.2

To a large extent as seen in the earlier period, productivity growth was driven by an improvement in technology, i.e. a shift in the best practice frontier in 2005-2006 however, decreased efficiency caused a overall decrease in productivity for 45 hospitals (see Table 2).

Table 2. Causes of Productivity decreases or increases

Productivity		due to both ECH and TCH decrease (increase)	due only to ECH decrease (increase)	due only to TCH decrease (increase)
2003~2004	-	27	18	20
	+	(10)	(26)	(12)
2004~2005	-	32	6	20
	+	(10)	(35)	(10)
2005~2006	-	5	45	7
	+	(11)	(3)	(42)
2003~2006	-	15	41	8
	+	(15)	(7)	(27)

Note: (1) All Figures denote the number of Hospital. Figures in parentheses are for the “increase”.

In a broad economic sense, technological change (innovation) – the main driver of productivity growth – is related to investment, i.e., a change in capital stock. Capital accumulation occurs when hospitals invest in more or better machinery, equipment, and structures that make it possible for them to produce more output. Capital accumulation, which determines the adoption of technology by best practice hospitals, thereby shifts the efficiency frontier. In Ontario the hospital sector was marked by an increased investment in equipment, and in clinical information technology, though the number of hospital beds remained almost constant over the sample period. The industry also experienced increased patient complexity and more expenses associated with increased compensation to medical staff nurses, which is a proxy of human capital. All this is consistent with the observed positive technological change, which in turn lead to productivity growth, despite some deterioration in technical efficiency.

It might be also worth noting here that during the study period, Ontario provincial governments were making significant investments in the health care sector through medical equipment, new drugs and treatment and consolidating a number of specialized activities, such as cancer care, in a few key specialized facilities.[5] The tendency has been toward capital investment too, because of ongoing shortages of health care professionals, which has promoted efforts to substitute capital for labour in the production process. It might also be the case that higher technological change in Ontario hospitals in 2005-2006 was induced by demand with an increasing trend of inpatient days during this particular period.

5. Estimation Results: Distributions of MPI and of its Components

Some of the estimated density figures are presented in the text and the rest are placed in the Appendix I. To determine whether the generated distributions have changed location or shape, and to assess the statistical significance of these differences, we use a version of the Li [34]-test, adapted to the DEA context by Simar and Zelenyuk [60]. In particular, we are interested in assessing changes in the distributions over time as well as across different types of hospitals, by stratifying all hospitals into rural[6] vs. urban, and small[7] vs. large. Tables 3 and 5 present the results. We have also tested the

[5] Rapoport *et al.* [52] noted that technological change in medical care is often associated with new equipment, new forms of organization, surgical procedures, drugs or methods of patient management. They further noted that changing demand can alter technology without any scientific progress.
[6] The rural category includes both rural and sub-urban hospitals.

equality of means, medians and variances of distributions between the time periods and across the different groups of hospitals. The results are presented in Tables 4 and 6.

Differences in productivity, efficiency and technology over time

Productivity Change

From Table 3 we see that across the time periods the distributions of (productivity scores from) MPI are not significantly different (here and after, in statistical sense).[8] The equality of means, medians and variances of MPI across the time periods are also not significant, and thereby do not reject the null hypothesis. The distributional results suggest that there is no evidence of significant improvement in hospital productivity over the sample period rather some hospitals improved productivity, others worsened and net result was that the overall distribution of MPI did not change significantly (see also Figure 1A in Appendix I). Though technological improvement dominates the change in productivity, a decline in efficiency in 2005-2006 offset the effect of increased technology on the distribution of MPI (see Figure 1).

Table 3. Simar-Zelenyuk-adapted Li Test for MPI, ECH, and TCH distributions between time periods

H_0 (f is density)	Test statistics	Bootstrap P-value	Decision on H_0
f(MPI 2003-2004) = f(MPI 2004-2005)	1.015	0.125	Do not reject H_0
f(MPI 2004-2005) = f(MPI 2005-2006)	0.575	0.440	Do not reject H_0
f(MPI 2003-2004) = f(MPI 2005-2006)	-0.222	0.792	Do not reject H_0
f(ECH 2003-2004) = f(ECH 2004-2005)	-0.354	0.651	Do not reject H_0
f(ECH 2004-2005) = f(ECH 2005-2006)	14.333	0.000	Reject H_0
f(ECH 2003-2004) = f(ECH 2005-2006)	11.609	0.000	Reject H_0
f(TCH 2003-2004) = f(TCH 2004-2005)	2.501	0.011	Reject H_0
f(TCH 2004-2005) = f(TCH 2005-2006)	31.799	0.000	Reject H_0
f(TCH 2003-2004) = f(TCH 2005-2006)	25.308	0.000	Reject H_0

Notes: 1. The test statistics is computed using Matlab code of Simar-Zelenyuk [60]
2. Bandwidth selected is done via the Silverman [59] rule of thumb; B= 5000

Table 4. Test Statistics of Mean, Median and Variance of MPI, ECH and TCH between time periods

Year	MPI	ECH	TCH

[7] The definition of small hospital is one with 2000 or less weighted cases.

[8] In part, this might be due to relatively small sample size compared to the dimension of the DEA model and so the test did not attain enough power to reject the null hypothesis.

	t	χ^2	F	t	χ^2	F	t	χ^2	F
2003-2004 vs 2004-2005	- 1.452 (0.148)	0.442 (0.506)	0.003 (0.953)	- 2.139 (0.034)	0.638 (0.424)	0.384 (0.536)	1.181 (0.239)	0.442 (0.506)	6.255 (0.013)
2004 -2005 vs 2005-2006	0.035 (0.972)	0.018 (0.894)	0.265 (0.607)	9.015 (0.000)	46.035 (0.000)	4.358 (0.038)	- 11.049 (0.000)	104.938 (0.000)	47.410 (0.000)
2003-2004 vs 2005-2006	-1.263 (0.208)	0.041 (0.839)	0.223 (0.637)	7.189 (0.000)	29.967 (0.000)	7.725 (0.006)	- 9.670 (0.000)	39.504 (0.000)	23.839 (0.000)

Notes: 1. t - test for equality of means, chi-sq test for equality of median and Levene's test (F-value) for equality of variances. 2. Numbers in parentheses are p-value at 5% level of significance.

Efficiency Change

Comparing distributions of ECH between years 2004/2005 & 2005/2006, and 2003/2004 & 2005/2006 we find significant differences (see Figure 3). Closer inspection of the density graphs reveals that change is coming from the differences in means, and medians as well as variances (and perhaps other moments). The ECH in hospital services in 2005-2006 decreased with wider variation resulting in a leftward shift in the density curve. This implies not only that the efficiency of hospitals declined with each year as we noted from the previous analysis, but that the whole distribution of efficiency has deteriorated over time, i.e., the density not only shifted to the left but also became more disperse, with just a few having positive efficiency change and majority having negative efficiency change (see Figure 3).

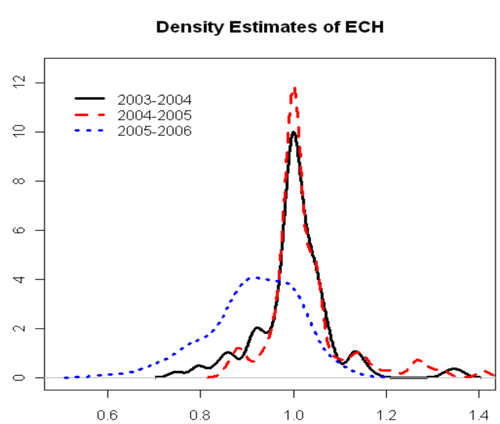

Figure 3.

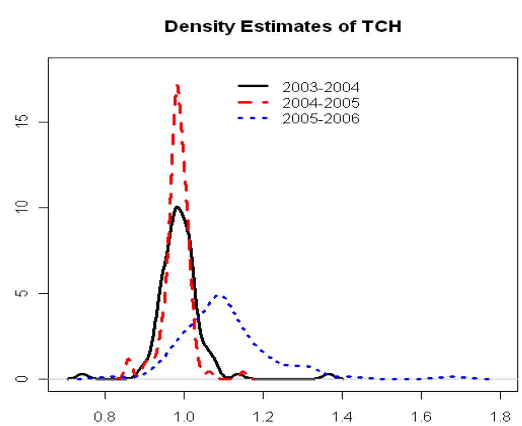

Figure 4.

Technology Change

From our results we see that there were significant differences with regard to the distribution of TCH between different time periods (see Figure 4). In 2005-2006 the density curve of TCH moved right-ward with a wider variation, reflecting higher technological progress in hospitals (see Figure 4). The differences in distributions of TCH between the time periods 2004-2005 and 2005-2006 were coming from significant differences in mean, median and variances (see Table 4). From Figure 4 we observe that the distribution of TCH (technological change) not only shifted to the right but also became much more dispersed, with majority of hospitals experiencing technological improvements, some experiencing dramatic improvements while only a few had negative change.

Differences in productivity, efficiency and technology by hospital type:

Rural vs. Urban Hospitals

In both 2004-2005 and 2005-2006, the distribution of MPI in urban hospitals was statistically different from that of rural hospitals and came primarily from the differences in variance (see Table 6). Rural hospitals in both periods had a somewhat symmetric distribution of MPI with wider variation (see Figures 2A and 5A in Appendix I and Table 2A in Appendix II).

In the earlier periods (2003-2004 and 2004-2005) the distribution of ECH in urban hospitals was also significantly different from their rural counterparts (see Figures 6A and 8A in Appendix I), due to differences in the median in 2003-2004 and differences in variance in 2004-2005 (see Table 6). Between 2003-2004 and 2004-2005 the distributions of ECH for rural and urban hospitals seemed to have reversed (i.e., distributions of ECH transformed into more symmetric from less symmetric in the case of rural hospitals and less symmetric from more symmetric in the case of urban hospitals), suggesting that rural hospitals experienced more catching-up while efficiency in urban hospitals deteriorated (see Figures 13A and 14A in the Appendix I). But in 2005-2006 distributions of ECH of both rural and urban hospitals transformed into more symmetric with wider dispersion and moved left, suggesting the deterioration of efficiency over time. However, compared to rural hospitals, urban hospitals experienced more deterioration in efficiency over time perhaps due to their larger size, raising the possibility of diseconomies of scale. The higher technical efficiency of rural hospitals compared to urban counterpart can be explained by the lower consumption of resources that usually takes place in rural areas.[9] Interestingly, the distribution of TCH between urban and rural hospitals was not significantly different in any period except 2004-2005 (see Figure 12A in Appendix I), when there were differences in both mean and variance (see Table 6).

Over the time period, productivity in both urban and rural hospitals was dominated by technological progress. The fact is that with almost constant inpatient days over the time period, urban hospitals treated an increasing number of ambulatory patients and incurred more expenses in the areas of medical, surgical and equipment. With an almost constant number of staffed beds, urban hospitals also experienced increased nursing hours perhaps to cope with increased patient complexity. Occupancy rates in both urban and rural hospitals fluctuated over time (in 2004 occupancy rate decreased in both type of hospitals), but were higher at the end of the study period. Average length of stay in urban hospitals decreased over time while rural hospitals faced an increasing trend in length of stay. This is consistent with the finding in Färe *et al.* (1994a) who noted that hospitals reporting decreases (increases) in average length of stay experienced regress (increase) in their best practice frontier.

Table 5. Simar-Zelenyuk-adapted Li test for MPI, ECH and TCH across different types of hospitals

H_0 (f is density)	Test statistics	Bootstrap P-value	Decision on H_0
2003-2004			
$f(MPI_{\text{urban hospitals}}) = f(MPI_{\text{rural hospitals}})$	0.495	0.487	Do not reject H_0
$f(MPI_{\text{small hospitals}}) = f(MPI_{\text{large hospitals}})$	0.250	0.748	Do not reject H_0
2004-2005			
$f(MPI_{\text{urban hospitals}}) = f(MPI_{\text{rural hospitals}})$	5.771	.000 2	Reject H_0
$f(MPI_{\text{small hospitals}}) = f(MPI_{\text{large hospitals}})$	1.774	0.035	Reject H_0
2005-2006			
$f(MPI_{\text{urban hospitals}}) = f(MPI_{\text{rural hospitals}})$	3.924	0.001	Reject H_0
$f(MPI_{\text{small hospitals}}) = f(MPI_{\text{large hospitals}})$	3.825	0.002	Reject H_0
2003-2004			
$f(ECH_{\text{urban hospitals}}) = f(ECH_{\text{rural hospitals}})$	2.063	0.022	Reject H_0
$f(ECH_{\text{small hospitals}}) = f(ECH_{\text{large hospitals}})$	2.649	0.011	Reject H_0
2004-2005			
$f(ECH_{\text{urban hospitals}}) = f(ECH_{\text{rural hospitals}})$	1.304	0.063	Reject H_0
$f(ECH_{\text{small hospitals}}) = f(ECH_{\text{large hospitals}})$	0.763	0.256	Do not reject H_0

[9] We thank anonymous referee for pointing this out.

2005-2006			
f(ECH$_{urban\ hospitals}$) = f(ECH$_{rural\ hospitals}$)	0.563	0.427	Do not reject H_0
f(ECH$_{small\ hospitals}$) = f(ECH$_{large\ hospitals}$)	2.039	0.021	Reject H_0
2003-2004			
f(TCH$_{urban\ hospitals}$) = f(TCH$_{rural\ hospitals}$)	0.274	0.720	Do not reject H_0
f(TCH$_{small\ hospitals}$) = f(TCH$_{large\ hospitals}$)	2.192	0.022	Reject H_0
2004-2005			
f(TCH$_{urban\ hospitals}$) = f(TCH$_{rural\ hospitals}$)	2.371	0.016	Reject H_0
f(TCH$_{small\ hospitals}$) = f(TCH$_{large\ hospitals}$)	2.731	0.012	Reject H_0
2005-2006			
f(TCH$_{urban\ hospitals}$) = f(TCH$_{rural\ hospitals}$)	-0.033	0.965	Do not reject H_0
f(TCH$_{small\ hospitals}$) = f(TCH$_{large\ hospitals}$)	-0.294	0.692	Do not reject H_0

Note: Notes: 1. The test statistics is computed using Matlab code of Simar-Zelenyuk [60]
2. Bandwidth selected is done via the Silverman [59] rule of thumb; B= 5000

Table 6. Test Statistics of Mean, Median and Variance of MPI, ECH and TCH across different groups of Hospitals

Group of Hospitals		rural vs urban			small vs large		
		2003-2004	2004-2005	2005-2006	2003-2004	2004-2005	2005-2006
MPI	t	0.010 (0.992)	1.035 (0.303)	0.111 (0.912)	- 0.772 (0.442)	- 2.109 (0.037)	- 0.621 (0.536)
	χ^2	0.730 (0.393)	0.428 (0.513)	1.516 (0.218)	0.093 (0.760)	0.712 (0.399)	0.093 (0.760)
	F	3.551 (0.062)	**33.052 (0.000)**	**15.663 (0.000)**	8.702 (0.004)	**27.442 (0.000)**	**17.607 (0.000)**
ECH	t	-1.550 (0.124)	**1.824 (0.071)**	0.920 (0.360)	0.572 (0.569)	- 2.932 (0.004)	- 1.381 (0.170)
	χ^2	11.419 (0.001)	1.516 (0.218)	1.063 (0.303)	6.768 (0.009)	0.093 (0.760)	2.592 (0.107)
	F	1.315 (0.254)	**29.315 (0.000)**	**3.133 (0.079)**	1.740 (0.190)	27.174 (0.000)	4.637 (0.033)
TCH	t	2.317 (0.022)	**- 1.693 (0.093)**	- 0.988 (0.325)	**- 2.111 (0.037)**	1.555 (0.123)	0.867 (0.388)
	χ^2	0.428 (0.513)	1.516 (0.218)	1.516 (0.218)	0.212 (0.645)	1.147 (0.284)	1.147 (0.284)
	F	2.689 (0.104)	**8.890 (0.004)**	0.004 (0.952)	**6.330 (0.013)**	**12.446 (0.001)**	0.583 (0.447)

Notes: 1. t - test for equality of means, chi-sq test for equality of median and Levene's test (F-value) for equality of variances
2. Figures in parentheses are p-value at 5% level of significance.

S*mall vs. Large Hospitals*

Due to the differences in variances (see Table 6), the distribution of MPI was also significantly different when comparing hospitals by size (small vs. large hospitals) in both 2004-2005 and 2005-2006 (see Figures 3A and 4A in the Appendix I). In both 2003-2004 and 2005-2006 the distributions of ECH in small hospitals were significantly different from those large hospitals. The differences in distributions in 2003-2004 between small and large hospitals came from the differences in the median (see Table 6). While the difference in the distribution of ECH in 2005-2006 was due to a difference in the variance only (see Table 6). There was a deterioration in efficiency for both small and large hospitals, small hospitals experienced more catching up compared to large hospitals (see Figures 15A and 16A in Appendix I).

The distribution of TCH (technological change) in small hospitals was significantly different from large hospitals from 2003 to 2005. Some small hospitals achieved higher technological progress and also catching-up (movement toward the frontier) compared to large hospitals in 2003-2004 but over the whole period they encountered more technological regress and decreased efficiency. This is because most rural and northern hospitals are small & operate independently of one another, so it is more difficult for them to achieve clinical and administrative efficiencies and they tend to be less likely to receive or to undertake investments in new technology. Moreover, due to their remote location, cost reducing strategies such as shifting inpatients to ambulatory care or volume purchasing are not a viable options for the small hospitals.

We also found that size had an impact on direct and indirect costs. Specifically we found that: 1) both overhead and direct costs were higher for smaller hospitals, 2) the effect of size as more dramatic for overhead expenditure than for direct cost and, 3) there was greater variation in overhead expenditure than for direct cost.[10]

6. Conclusion

In this paper we introduced recent advances in productivity analysis using non-parametric kernel density estimation applied to the MPI and its decomposition obtained through DEA. We also applied the bootstrap based Simar-Zelenyuk-adapted Li -test to make inferences about the distribution of MPI and its decomposition across the different types of hospitals and over time.

[10] For more details see Nizar Ladak [45].

During the period 2003-2004 to 2005-2006, productivity increased from 0.984 to 0.999. Over the sample period efficiency decreased from 0.998 to 0.911 and technology increased from 0.986 to 1.097. From Simar-Zelenyuk adapted Li –test we found that there was no statistically significant improvement in hospital productivity in Ontario over the whole study period, though in some periods productivity scores were significantly different by hospital size and geographical location. Productivity changes were driven by technological change (outward shift in the best practice frontier) rather than by changes in efficiency (catching-up to the frontier). Though technological improvement is important for the overall delivery of health care services; we can not take full advantage of technologies unless the resources are employed efficiently. Rather than overall efficiency increases, consistent with Aaron [1], Newhouse [43], Schwartz and Mendelson [54] we found that over the sample period, many Ontario hospitals lagged behind the technical efficiency in that they were operating well below the frontier. Inefficiency may result from both inefficient utilization of resources and or failure to produce at the optimum scale. We found that a large number of hospitals were subject to diseconomies of scale, which tends to be associated with difficulty in managing and coordinating resources in larger facilities. Though there may be benefits to concentrating investment and expertise in larger centres, there might also be a cost in terms of reduced efficiency. More importantly, the dualism[11] in the technology should be avoided among hospitals as it might lead to backwash effect and to further deterioration in efficiency. It is also important that with a given technology inputs should be used efficiently, e.g., through accumulation of knowledge, changing combinations of inputs or production processes, improved managerial practice, and so forth, so that output will increase and more and more hospitals experience catching-

[11] 'Dualism' in technology refers to the co-existence of both relatively old and modern technology. That means within a group there are two distinct classes: one is running with very new medical technology and the other is using not older medical technology. Within our sample of hospitals we found that the Technology Index varied from 4 to 7. The sum of Technology Index indicator ranges from 0 to 8, with 0 (0,1,2…,7,8) representing the minimum level (or age) of technology used in Diagnosis and Treatment. If both small and large hospitals have the same technology but that large hospitals adopt a very new modern technology and due to this advancement in technology in large hospitals there might be a negative effect on small hospitals in terms of decline in hospital output.

up.[12] Of course, hospitals operating under increasing returns to scale could perhaps be more efficient by increasing capacity but there are additional social objectives which come into play, such as ensuring adequate access to care, training and research functions. One implication of this is that more emphasis should perhaps be placed on increasing efficiency through managerial and organizational improvements so that the benefits of technological advancement and its positive impact on overall productivity and performance of hospitals would be sustainable over the long run.

Future research should consider integration of quality of care indicators to further characterize hospitals outputs. An alternative approach based on DRG-type case mix system reflecting patient mix among different groups of hospitals would also be an interesting subject for future research.

Our results suggest that comparing the sample means of efficiency scores of two or more groups of hospitals may not provide a complete picture. Sample means of efficiency scores ignore the relative weight of each group in the sample. The natural extension of this work would be to estimate aggregate efficiency and an aggregate Malmquist productivity index and its components accounting for the relative size of each group.

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[12][12] See also Mahadevan [40].

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APPENDIX I

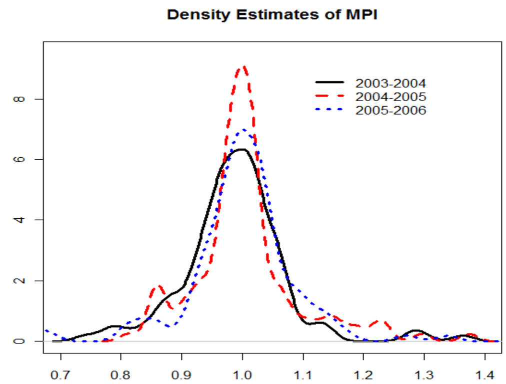

Figure 1A

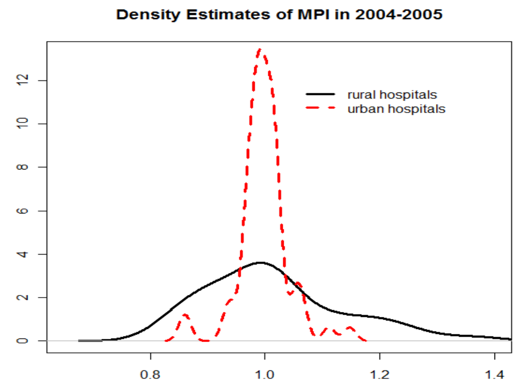

Fig 2A. Note: P-value: 0.0002

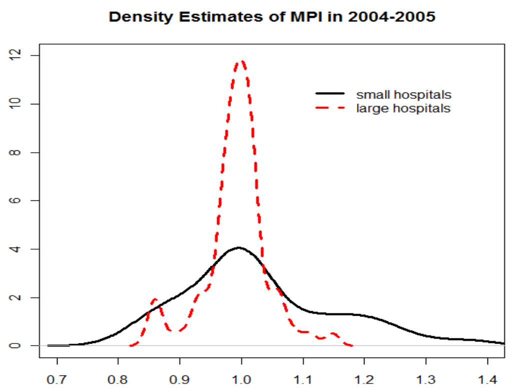

Fig 3A. Note: P-value: 0.0354

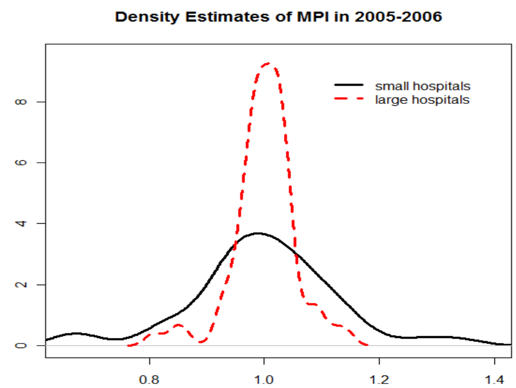

Fig 4A. Note: P-value: 0.0020

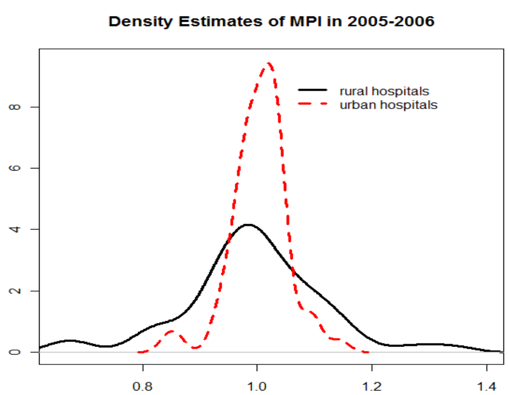

Fig 5A. Note: P-value: 0.0012

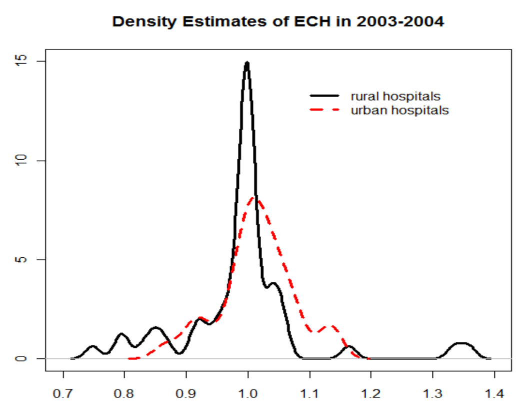

Fig 6A. Note: P-value: 0.0228

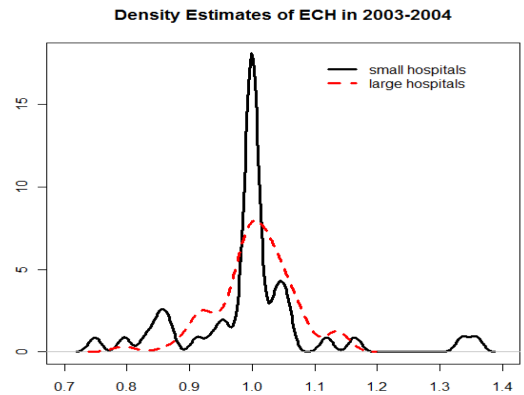

Fig 7A. Note: P-value: 0.0116

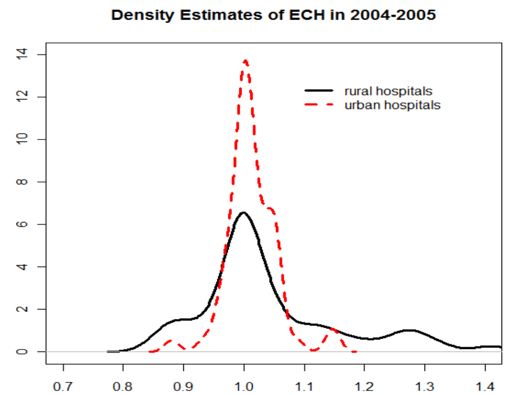

Fig 8A. Note: P-value: 0.0630

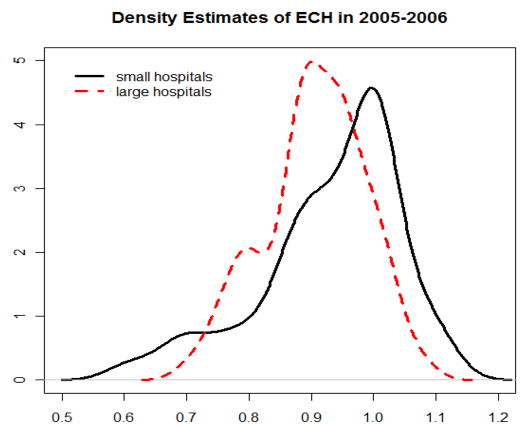

Fig 9A. Note: P-value: 0.0216

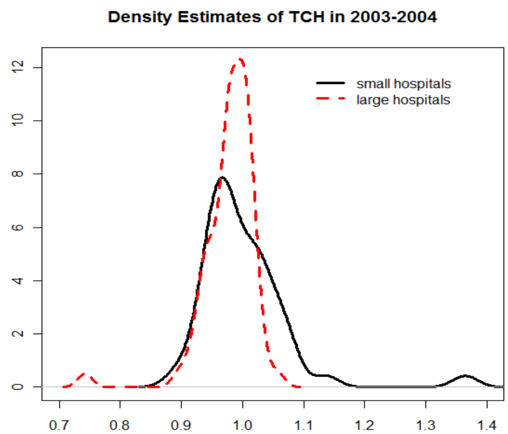

Fig 10A. Note: P-value: 0.0220

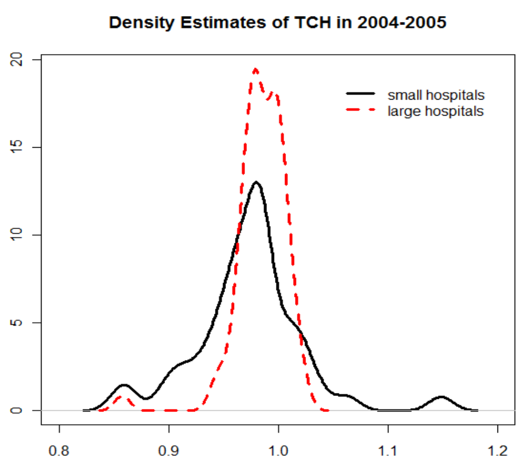

Fig 11A. Note: P-value: 0.0128

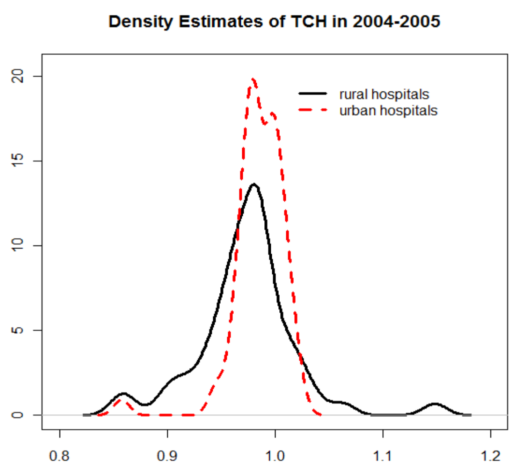

Fig 12A. Note: P-value: 0.0168

Density Estimates of ECH in rural Hospitals over time

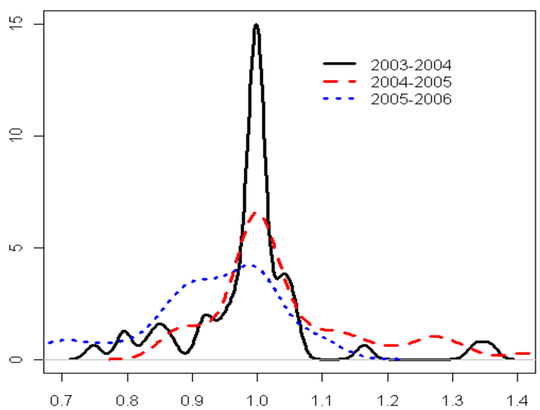

Fig 13A.

Density Estimates of ECH in urban Hospitals over time

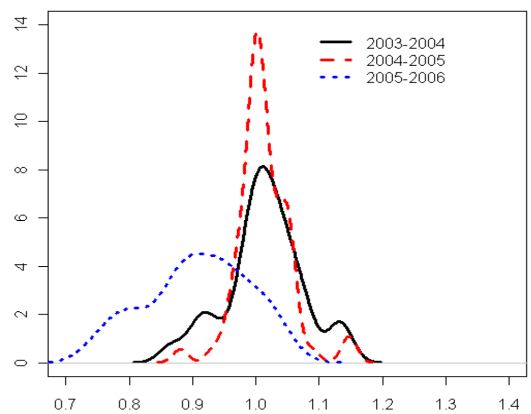

Fig 14A.

Density Estimates of ECH in small Hospitals over time

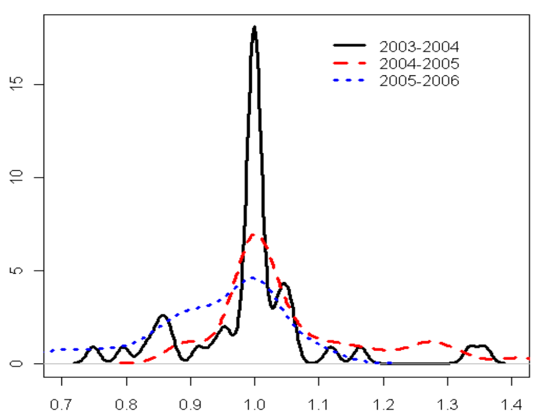

Fig 15A.

Density Estimates of ECH in large Hospitals over time

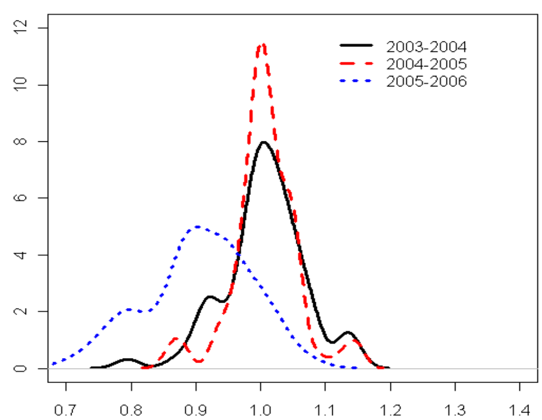

Fig 16A.

Appendix II

Table 1A
Descriptive Statistics of MPI, ECH, and TCH over the time periods

Statistics	year	MPI	ECH	TCH
mean	2003-2004	0.985	0.998	0.986
	2004-2005	1.002	1.023	0.979
	2005-2006	0.999	0.910	1.097
	2003-2006	0.986	0.930	1.059
median	2003-2004	0.988	1	0.984
	2004-2005	0.997	1.00	0.981
	2005-2006	0.999	0.927	1.093
	2003-2006	0.986	0.938	1.054
st. Dev	2003-2004	0.088	0.083	0.058
	2004-2005	0.090	0.088	0.036
	2005-2006	0.110	0.095	0.112
	2003-2006	0.152	0.129	0.116
minimum	2003-2004	0.742	0.748	0.742
	2004-2005	0.811	0.858	0.855
	2005-2006	0.667	0.608	0.818
	2003-2006	0.574	0.608	0.726
maximum	2003-2004	1.365	1.358	1.365
	2004-2005	1.375	1.411	1.148
	2005-2006	1.683	1.112	1.683
	2003-2006	1.739	1.543	1.566

Table 2A. Descriptive Statistics of MPI, ECH, and TCH across the different groups of hospitals

Statistics	Year	MPI		ECH		TCH	
		rural	urban	rural	urban	rural	urban
mean	2003-2004	0.988	0.988	0.989	1.013	1.001	0.976
	2004-2005	1.015	0.997	1.042	1.012	0.974	0.985
	2005-2006	1.006	1.004	0.924	0.908	1.091	1.112
median	2003-2004	0.983	0.996	1.000	1.016	0.985	0.982
	2004-2005	1.001	0.994	1.000	1.005	0.980	0.984
	2005-2006	0.994	1.008	0.941	0.911	1.085	1.100
variance	2003-2004	0.012	0.004	0.011	0.003	0.004	0.002
	2004-2005	**0.015**	**0.002**	0.014	0.001	0.002	0.000
	2005-2006	**0.023**	**0.002**	0.012	0.006	0.016	0.009
		small	large	small	large	small	large
mean	2003-2004	0.996	0.983	0.996	1.005	1.001	0.978
	2004-2005	1.027	0.991	1.055	1.007	0.973	0.984
	2005-2006	1.013	1.000	0.931	0.905	1.091	1.110
median	2003-2004	0.986	0.989	1.000	1.003	0.984	0.983
	2004-2005	1.005	0.993	1.000	1.002	0.980	0.983
	2005-2006	0.997	1.005	0.952	0.906	1.077	1.096
variance	2003-2004	0.013	0.004	0.011	0.003	0.005	0.001
	2004-2005	0.015	0.002	0.014	0.002	0.002	0.000
	2005-2006	0.025	0.003	0.012	0.006	0.018	0.008