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Taiwan quality indicator project and hospital productivity growth

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ABSTRACT

The Taiwan Quality Indicator Project (TQIP) is a quality management program that measures and monitors the healthcare quality of hospitals in Taiwan. This paper examines the impact of TQIP participation on hospital productivity growth with the application of the Malmquist productivity change index based on data envelopment analysis (DEA). Analyzing operations data from 31 TQIP regional hospitals over the period 1998–2004, we find that TQIP hospitals improved their productivity in the post-TQIP period. This improvement is attributable to quality change and relative efficiency progress. The simultaneous enhancement in both quality and relative efficiency coincides with the philosophy of total quality management (TQM) spirit, and confirms the efficiency improvement and quality assurance functions of TQIP.

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1. Introduction

The growing trends of rising healthcare costs and increasingly aging population have forced the government and healthcare providers to be more concerned with healthcare resources productivity [1,2] and quality [3–8]. However, an inefficient utilization of healthcare resources has been one of the major reasons for inflated spending on healthcare services [9]. This inefficient use of resources, in conjunction with a greater consciousness of the importance of healthcare system reform has led to more scrutiny of the cost effectiveness of healthcare delivery services [4,10]. To promote cost-effectiveness, nearly 70% of US hospitals have implemented total quality management (TQM) and continual quality improvement (CQI) programs [11]. Bosworth et al. [12] validated that progress in quality improvement contributed to the productivity growth.

In 1999, the Department of Health of Taiwan established the Taiwan Joint Commission on Hospital Accreditation (TJCHA) whose ultimate goal is to integrate and upgrade the healthcare quality system. Based on the successful experience and international benchmarking of the Maryland Quality Indicator Project (MQIP) and International Quality Indicator Project (IQIP), TJCHA initiated the Taiwan Quality Indicator Project (TQIP) in 2000 to pursue its mission of excellence in healthcare quality. In particular, TJCHA adapted the following three types of quality

indicators for TQIP: acute care indicators, psychiatric care indicators, and long-term care indicators [13]. The Department of Health of Taiwan also encouraged hospitals to collect and utilize the acute care indicators to facilitate improvements in healthcare quality and productivity.

In this study, we evaluate the productivity changes of Taiwanese hospitals after joining the TQIP in 2000 using the Malmquist [14] productivity change index based on non-parametric data envelopment analysis (DEA). Prior studies have shown the flexibility of DEA over traditional parametric methods in estimating hospital productivity [15,16]. The Malmquist productivity change index can be used to track the specific position corresponding to each hospital and to examine changes in productivity and quality [17]. Färe et al. [18] advanced the Malmquist productivity index to measure changes in the following three components of productivity growth: quality change, efficiency change, and technical change. The use of the Malmquist productivity change index enables us to identify individual components of changes in hospital productivity, especially changes in efficiency and quality [17].

Prior studies on healthcare productivity have focused on organizational determinants, technology involvement and policy intervention [7,9,19,20]. They estimated the input–output correspondence and typically ignored the potential impact of healthcare quality indicators such as outcomes on productivity measurement due to lack of quality indicators. We attempt to overcome this problem by incorporating the quality indicator in our estimation. Specifically, we examine productivity change and its three components (quality change, relative efficiency change, and technical change) from the pre-TQIP period to the post-TQIP period.

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Analyzing operations data from 31 TQIP regional hospitals in Taiwan from the pre-TQIP period (1998) to the post-TQIP period (2002 and 2004), we find that TQIP hospitals demonstrated significant productivity growth in the post-TQIP period. This growth is attributable to quality change and relative efficiency progress, meeting the TJCHA's expected goal. Our results also indicate that efficiency and quality improve simultaneously after TQIP participation, which coincides with the philosophy of total quality management (TQM) and confirms the efficiency improvement and quality assurance functions of TQIP.

The remainder of this paper is presented as follows. Section 2 provides background, including the definition of healthcare quality, description of the Taiwan Quality Indicator Project (TQIP), and a brief review of related literature on healthcare quality and hospital productivity to motivate research hypotheses. Section 3 presents the research design including description of sample data and construction of the Malmquist productivity change index using DEA models. Section 4 presents and discusses the empirical results and Section 5 concludes the paper.

2. Background and research hypotheses

2.1. Healthcare quality

According to the US Institute of Medicine (IOM), the definition of quality is “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge”. The US Office of Technology Assessment (OTA) also indicates that the quality of care should focus on ideal patient healthcare by applying contemporary healthcare knowledge and decrease the degree of malpractice. Donabedian [21] further defined quality care as being that which is expected to maximize patient welfare, after taking into account the expected gains and losses attendant to the process of care in all its parts, by constructing a patient-centered concept of healthcare quality.

The most commonly adopted model in healthcare quality measurement is the three-step framework, *structure–process–outcome*, proposed by Donabedian [22]. This framework is similar in spirit to the *input–process–output* framework used in a manufacturing setting. The procedure of healthcare is logically divided into the above-mentioned three steps with individual indicators for performance evaluation and comparison. Traditional healthcare quality evaluation has focused on structural perspectives, such as hospital size, the quantity of facilities and equipment, and the quantity of services provided. Until 1986, the US Health Care Financing Agency (HCFA) presented the mortality of each hospital as a quality indicator and this outcome indicator subsequently became a new trend in healthcare quality evaluation [23].

2.2. Taiwan Quality Indicator Project (TQIP)

In 1995, the Department of Health in the Executive Yuan of Taiwan implemented the National Health Insurance (NHI) program, which introduced a uniform payment system within a given category of homogeneous hospitals. The Department of Health further established the Taiwan Joint Commission on Hospital Accreditation (TJCHA) in 1999. There are four stated missions for the TJCHA, comprising of: (1) assisting and promoting national medical quality policies; (2) determining medical quality certification standards; (3) consulting with healthcare

organizations; and (4) promoting the relationship between the hospitals and the patients. The ultimate goal is to integrate and upgrade the overall quality of the healthcare system. There have been several programs implemented by TJCHA, including Hospital accreditation, Healthcare Quality Improvement Circle (HQIC), and Healthcare Quality Learning Organization. Making successful experience and international benchmarking reference to the International Quality Indicator Project (IQIP), TJCHA initiated the Taiwan Quality Indicator Project (TQIP) in 2000 to meet the requirements of its fourfold mission. By 2004, there had been 72 hospitals joined TQIP.

The IQIP developed quality performance indicators to facilitate participating hospitals' efforts to benchmark and improve performance. In 2007, 575 healthcare organizations in 13 countries used the IQIP tools to collect, analyze, and compare clinical and administrative healthcare data. IQIP participants receive quarterly data reports, which allow for longitudinal trending and comparison to national, regional, and international aggregate rates. The motivating factor behind the IQIP is not just the collection of data, but in analyzing the underlying causes that lead to certain outcomes. The aims of the IQIP are to develop educational materials, to conduct user groups and educational sessions in the field, to learn from the efforts of IQIP participants to understand and put their data to work, and to assist in participants' benchmarking and networking activities.

According to TJCHA [13], based on prior international quality assessment practices, those hospitals joining the International Quality Indicator Project (IQIP) would move through a three-stage transition process: (1) establishing documentary quality indicators, (2) assessing and improving these indicators, and (3) attaining continuous healthcare quality improvement and enhancement. Due to such changes in organizational adjustment over time, short-term performance impact may differ from longer-term impact. For example, treatment cost may increase initially following quality improvement adoption because of changes in long-standing organizational routines and investment in data systems and other elements of QI infrastructure. However, organizational performance may, over a sufficiently long period of time, result in net savings and improved economic efficiency [24].

For TJCHA, the TQIP is an independent and objective benchmarking platform for healthcare in Taiwan. Through IQIP, successful and international experience is applied and local regular and periodic monitoring indicators are established. For participants, there are several benefits to join TQIP including: TQIP task force to healthcare professional consulting, continuous educational trainings, various related seminars and consortiums to share and learn, quarterly quality reports released, data collection database, and quarterly report feedback. There are objective performance evaluations and ad hoc continuous improvement programs for participants. The local healthcare providers enable to apply TQIP data and information to develop their own quality improvement approaches and meet the national and international norms for accreditation.

2.3. Healthcare quality and productivity

The major goal of healthcare or healthcare reform should be the maximization of the welfare of treated patients, in pursuit of better healthcare quality. Quality of healthcare should derive from the dedication and good intent of well-trained and motivated healthcare providers [25]. However, quality is an abstruse term. With limited financial resources and growing patient demands, cost-efficiency concerns tend to prevail over

quality considerations. There seems to be a constant debate over the trade-off between quality and efficiency. Currently, there does not seem to be any consensus on the link between quality elevation and efficiency improvement. Over the last decade, total quality management (TQM) has emerged as a possible solution to improve the efficiency and effectiveness of health-care [26].

Numerous studies have investigated related issues from different aspects. For instance, Longest [27] applied adjusted acute care mortality, physician ratio, and medical supporting personnel self-score as quality indicators. Longest [27] reported that there was a negative relationship between quality and cost. Fleming [28] also examined the quality and cost by using the adjusted re-hospitalization rate and mortality and observed a non-linear relationship between quality and cost. Cleveley and Harvey [29] explored the relationship between healthcare quality and profit rates, and indicated that the lower quality hospitals performed less well than their peers in profit rate, charge, cost of each inpatient discharge, ratio of fixed asset and revenue, and ratio of each inpatient discharge to personnel. However, there was only higher bed occupancy in lower quality hospitals. Harkey and Vraciu [30] discussed the relationship between quality and financial performance. They applied perceived quality, level of community wealth, hospital image, and scale as the independent variables, while marginal operational profit was treated as a dependent variable. The results demonstrated that only perceived quality had a positive and significant relationship with marginal operational profit.

In terms of productivity change measurement in healthcare services, Färe et al. [18] decomposed the Malmquist productivity change of Caves et al. [31,32] into quality change, efficiency change, and technical change. Färe et al. [18] sampled 257 Swedish pharmacies for the years 1990 and 1991. They observed that only quality change decreased whereas efficiency change and technical change improved greatly. Althin et al. [33] assessed the profitability change, using a mathematical model and the Malmquist productivity change index, for 361 Swedish pharmacies on the basis of two years' data. They documented that even though efficiency change deteriorated, a much greater improvement in technical change was seen.

Färe et al. [34] examined 19 healthcare providers within the Organization for Economic Co-operation and Development (OECD) from 1974 to 1989 and found that only Denmark and the United States presented productivity changes. Tambour [35] evaluated productivity change in 20 Swedish ophthalmology departments with the longest waiting times. The results indicated that there was no significant relationship between the waiting-time limitation and productivity change.

Margit [36] examined the impact of Austrian hospital financing reform on hospital productivity between 1994 and 1998. The samples include three years before the reform and two years after the reform. The results illustrated a considerably positive shift in technology between 1996 and 1998, whereas the intended enhancement in technical efficiency has not yet taken place. Miiika [37] analyzed the effect of healthcare financing reform on the productivity of hospital care in Finland during the period 1988–1994. The results show a significantly productivity change in 1992–1993 and 1993–1994, suggesting that the state subsidy reform in 1993 may have strengthened hospitals' effort to improve performance.

Sola and Prior [17] explored the productivity change and quality change in the Catalan Hospital for the years from 1990 to 1993. Even though the overall technical change decreased, both the quality change and the efficiency change showed improvements. Prior [38] explored the characteristics of the different technological ways to incorporate quality. The decomposition in

the Malmquist productivity index shows an improvement in productivity and a positive technical change, especially when quality is introduced.

As described earlier, the ultimate goal of TJCHA is to integrate and upgrade the overall quality of the healthcare system. Toward this end, TJCHA initiated the TQIP and provided various incentives¹ for hospitals triggering them to join the TQIP. Based on the above discussion, we posit that hospitals will improve their quality after joining the TQIP. Thus, we specify our first hypothesis as follows:

H1. TQIP hospitals improve their quality in the post-TQIP period.

The effective utilization of limited resources is a vital problem for healthcare management. The scarcity of healthcare resources is particularly concerned in developing countries where poor health condition is one of the most important obstacles in the fight for economic development and welfare [39]. Healthcare policies consider quality of care to be of paramount importance [40]. The Department of Health of Taiwan encouraged TQIP hospitals to collect and utilize the acute care indicators to facilitate improvements in healthcare quality and efficiency. After joining TQIP, hospitals are able to identify the non-value-adding processes, reduce costs, as well as obtain a thorough understanding of cost structure. They are also able to discover quality problems, comprehend the in-house quality status quo, improve data collection methods, and promote the quality philosophy. Therefore, we anticipate hospitals to improve their efficiency as well as productivity after joining the TQIP. We apply the Malmquist productivity change index to measure healthcare productivity change. The Malmquist productivity change index is decomposed into quality change, relative efficiency change, and technical change [18]. We anticipate the aggregate effect from the quality and efficiency progress would lead to productivity growth after the TQIP adaptation. Accordingly, we propose the following two research hypotheses:

H2. TQIP hospitals improve their efficiency in the post-TQIP period.

H3. TQIP hospitals improve their productivity in the post-TQIP period.

3. Research design

3.1. Description of data

At the end of 2004, there were 610 hospitals (excluding clinics) in Taiwan, of which only 72 had joined TQIP. Among the participating hospitals, 63 hospitals collected the acute care indicator data as recommended by TJCHA and the Department of Health of Taiwan. Depending on their primary functions, hospitals in Taiwan are divided into three basic levels: medical centers, regional hospitals, and district hospitals. The reimbursement schedule under the National Health Insurance (NHI) Act, while uniform within a given level of hospitals, varies by the level of hospitals. The type of patients serviced (hospital output) also varies within these different levels of hospitals. To ensure greater homogeneity in performance evaluation across comparable units, and taking into account sample size variations, we focus on examining the productivity change only for regional hospitals. There are 31 regional hospitals (15 public hospitals and 16 private hospitals joined the TQIP program in 2000) that provided complete data on acute care indicators for the years in

¹ Through the TQIP participation, hospitals improved their reputation and public trust as well as international linkage.

the pre-TQIP period (1998) and in the post-TQIP period (2002 and 2004).² In 2003, Severe Acute Respiratory Syndrome (SARS) originated in Hong Kong and China. Taiwan also had 664 cases, including 346 contagions and 73 dead. SARS had an important impact on healthcare and economics for Taiwan. Our study focuses on the changes in quality and productivity consequent to the adoption of TQIP, and we use the Malmquist productivity change index and its components to evaluate these changes from the pre-TQIP to the post-TQIP periods (1998–2002 and 1998–2004).

3.2. Malmquist productivity index and its components

The Malmquist productivity index measures changes in total outputs relative to inputs. It is originally derived from the ideas of Caves et al. [31]. Färe, Grosskopf, Lindgren, and Roos (FGLR) [41] decomposed the Malmquist index into technical change index and efficiency change index. Later, Färe, Grosskopf, and Roos (FGR) [18] incorporated “quality” (a) attributes into FGLR’s model and decomposed the Malmquist productivity index into three components, namely quality change, technical change, and efficiency change. Many studies have applied Malmquist productivity index [17,42–46] to measure productivity growth in various industries.

We adopt a modified version of the FGR [18] model to measure the Malmquist productivity index and its components. The Malmquist productivity index compares productivity change from the base period denoted by “0” (i.e., the pre-TQIP period) to the subsequent period denoted by “1” (i.e., the post-TQIP period) by calculating the ratio of the distances between the two periods based on a common production technology.

Let the technology set of period T be defined by production possibility set $S^T = \{(y, a, x) | y \text{ and } a \text{ can be produced from } x \text{ at time } T\}$, where x and (y, a) be the observed input and output vectors. Shephard’s [47] input distance function at period T is defined as $D_i^T(y^T, a^T, x^T) = \sup\{\theta : (x^T/\theta, y^T, a^T) \in S^T\} = (\inf\{\theta : (\theta x^T, y^T, a^T) \in S^T\})^{-1}$. Assume that the production set S^T , $T=0, 1$ is monotonically increasing and convex. The input-based Malmquist productivity index to compare the pre-TQIP ($t=0$) to the post-TQIP period ($t=1$) based on the “0” period production technology can be expressed as

$$M_i^{01}(y^1, a^1, x^1, y^0, a^0, x^0) = \frac{D_i^0(y^1, a^1, x^1)}{D_i^0(y^0, a^0, x^0)} \quad (1)$$

Multiplying $D_i^0(y^0, a^1, x^0)$ for both denominator and numerator in (1) yields,

$$\begin{aligned} M_i^{01} &= \left[\frac{D_i^0(y^0, a^1, x^0) D_i^0(y^1, a^1, x^1)}{D_i^0(y^0, a^0, x^0) D_i^0(y^0, a^1, x^0)} \right] \\ &= \left(\frac{D_i^0(y^0, a^1, x^0)}{D_i^0(y^0, a^0, x^0)} \right) \left(\frac{D_i^0(y^1, a^1, x^1)}{D_i^0(y^0, a^1, x^0)} \right) \end{aligned} \quad (2)$$

The first part of Eq. (2) measures the quality change from period “0” to period “1” based on the period “0” technology. The second part represents the change in productivity under two given attribute vectors. According to FGR [18], while the distance function may or may not be multiplicatively separable, their results are comparable. Thus, we follow FGR [18] and assume that the distance function is multiplicatively separable in attributes and inputs/outputs, as $D_i^0(y^0, a^1, x^0) = \beta^0(a^1) \hat{D}_i^0(y^0, x^0)$ and simi-

larly for the other period distance functions. We then rewrite the first part and the second part of Eq. (2) as follows:

$$\frac{D_i^0(y^0, a^1, x^0)}{D_i^0(y^0, a^0, x^0)} = \frac{\beta^0(a^1) \hat{D}_i^0(y^0, x^0)}{\beta^0(a^0) \hat{D}_i^0(y^0, x^0)} = \frac{\beta^0(a^1)}{\beta^0(a^0)}, \quad (3a)$$

and

$$\begin{aligned} \frac{D_i^0(y^1, a^1, x^1)}{D_i^0(y^0, a^1, x^0)} &= \frac{\beta^0(a^1) \hat{D}_i^0(y^1, x^1)}{\beta^0(a^1) \hat{D}_i^0(y^0, x^0)} = \frac{\hat{D}_i^0(y^1, x^1)}{\hat{D}_i^0(y^0, x^0)} \\ &= \frac{\hat{D}_i^1(y^1, x^1)}{\hat{D}_i^0(y^0, x^0)} \times \frac{\hat{D}_i^0(y^1, x^1)}{\hat{D}_i^1(y^1, x^1)} \end{aligned} \quad (3b)$$

Eq. (3b) is the Malmquist productivity index based on the production technology $S^T = \{(y, x) | y \text{ can be produced from } x \text{ at time } T\}$ and consists of relative efficiency change and technical change.

We incorporate “quality” attributes (a^t) and extend the Malmquist productivity change index (MI), decomposing into quality change (QC), relative efficiency change (EC), and technical change (TC) as

$$M_i^{01} = \frac{D_i^0(y^1, a^1, x^1)}{D_i^0(y^0, a^0, x^0)} = \frac{\beta^0(a^1)}{\beta^0(a^0)} \times \frac{\hat{D}_i^1(y^1, x^1)}{\hat{D}_i^0(y^0, x^0)} \times \frac{\hat{D}_i^0(y^1, x^1)}{\hat{D}_i^1(y^1, x^1)}$$

Thus,

$$M_i^{01} = \text{MI} = \text{QC} \times \text{EC} \times \text{TC} \quad (4)$$

Where

$$\text{QC} = \frac{\beta^0(a^1)}{\beta^0(a^0)}, \quad (5)$$

$$\text{EC} = \frac{D_i^1(y^1, x^1)}{D_i^0(y^0, x^0)}, \quad (6)$$

$$\text{TC} = \frac{\hat{D}_i^0(y^1, x^1)}{\hat{D}_i^1(y^1, x^1)}. \quad (7)$$

MI measures the growth in productivity from the pre-TQIP period to the post-TQIP period. QC measures the change in quality between these two periods. EC represents the change in efficiency relative to their peers, reflecting movement toward or away from the production frontier, and is referred to as the catching up to the frontier. TC is the technical progress capturing the shift in the production frontier [18]. A value less than unity in MI, QC, EC, and TC indicates an improvement in that measure from the pre-TQIP period to the post-TQIP period, and a value greater than unity indicates a deterioration in performance over time. Note that Eq. (4) indicates that these contributions to the growth in productivity are multiplicative rather than additive.

3.3. Estimation of Malmquist productivity change index

We use data envelopment analysis (DEA) to estimate Malmquist productivity change index, quality change, relative efficiency change, and technical change indexes. DEA has been proven to be an effective tool for evaluating the relative efficiency of peer decision making units (DMUs) when multiple performance measures are present [48–51]. We assume that there are $k=1, \dots, K$ observations of input $x^{k,t}$ at $t=0,1$ periods, as well as observations on outputs $y^{k,t}$ and quality output $a^{k,t}$. Since the

² There are 6 regional hospitals not willing to provide data in 2003 because of the severe situations of SARS contagions.

quality output is multiplicatively separable and shown as $D_i^0(y^0, a^1, x^0) = \beta^0(a^1) \hat{D}_i^0(y^0, x^0)$, we can calculate $\beta^0(a^1)$ as the ratio of $D_i^0(y^0, a^1, x^0) / \hat{D}_i^0(y^0, x^0)$. Following Banker et al. [51], we use the following BCC [52] models to estimate quality change (QC), relative efficiency change (EC), technical change (TC), and total productivity change (M^{01}) indices of specified observation k'

$$[(D_i^t(x^{k',t}, a^{k',t}, y^{k',t}))^{-1}] = \operatorname{argmin}\{\hat{\theta} \mid \sum_{k=1}^K \lambda^{k,t} x^{k,t} \leq \theta x^{k',t};$$

$$\sum_{k=1}^K \lambda^{k,t} y^{k,t} \geq y^{k',t}; \sum_{k=1}^K \lambda^{k,t} a^{k,t} \geq a^{k',t};$$

$$\sum_{k=1}^K \lambda^{k,t} = 1, \lambda^{k,t} \geq 0 \forall k = 1, \dots, K\}$$

$$[(\hat{D}_i^0(x^{k',0}, a^{k',1}, y^{k',0}))^{-1}] = \operatorname{argmin}\{\hat{\theta} \mid \sum_{k=1}^K \lambda^{k,0} x^{k,0} \leq \theta x^{k',1};$$

$$\sum_{k=1}^K \lambda^{k,0} y^{k,0} \geq y^{k',0}; \sum_{k=1}^K \lambda^{k,0} a^{k,0} \geq a^{k',1};$$

$$\sum_{k=1}^K \lambda^{k,0} = 1, \lambda^{k,0} \geq 0 \forall k = 1, \dots, K\}$$

$$[(\hat{D}_i^t(x^{k',t}, y^{k',t}))^{-1}] = \operatorname{argmin}\{\hat{\theta} \mid \sum_{k=1}^K \lambda^{k,t} x^{k,t} \leq \theta x^{k',t};$$

$$\sum_{k=1}^K \lambda^{k,t} y^{k,t} \geq y^{k',t}; \sum_{k=1}^K \lambda^{k,t} = 1, \lambda^{k,t} \geq 0, \forall k = 1, \dots, K\}$$

$$[(\hat{D}_i^0(x^{k',1}, y^{k',1}))^{-1}] = \operatorname{argmin}\{\hat{\theta} \mid \sum_{k=1}^K \lambda^{k,0} x^{k,0} \leq \theta x^{k',1};$$

$$\sum_{k=1}^K \lambda^{k,0} y^{k,0} \geq y^{k',1};$$

$$\sum_{k=1}^K \lambda^{k,0} = 1, \lambda^{k,0} \geq 0, \forall k = 1, \dots, K\}$$

3.4. Hospital inputs and outputs

We select appropriate hospital input and output variables for our DEA model based on prior literature [16,19,20,53]. Given the constraints of the available data, we select four inputs and four outputs for this study.

The input variables chosen for our analysis are: (1) the number of physicians (X1), which includes both physicians and Chinese medicine doctors; (2) the number of nurses (X2), which includes both registered professional nurses and other registered nurses; (3) the number of supporting medical and ancillary services personnel (X3), including pharmacists, assistant pharmacists, medical technologists, medical technicians, medical radiological technologists, midwives, and dietitians, and (4) the number of patient beds (X4), including general beds, special treatment beds, psychiatric beds, chronic beds, tuberculosis beds, and leprosy beds.

The output variables consist of: (1) the number of clinic or outpatient visits (Y1), including both ambulatory and emergency room visits; (2) the number of patients receiving surgery (Y2); (3) the number of patient days (Y3), including general care, acute and

Table 1
Descriptive statistics on inputs and outputs of hospitals (N=31).

Variables	Year	Mean	Std Dev	Median
<i>Panel A: Inputs</i>				
Number of physicians (X1)	1998	168	60	172
	2002	219	89	211
	2004	222	92	199
Number of nurses (X2)	1998	308	139	285
	2002	388	160	340
	2004	450	189	425
Number of supporting medical and ancillary services personnel (X3)	1998	209	130	171
	2002	326	153	301
	2004	322	171	295
Number of patient beds (X4)	1998	524	167	486
	2002	613	166	581
	2004	639	170	619
<i>Panel B: Outputs</i>				
Number of clinic or outpatient visits (Y1)	1998	463,046	202,568	452,303
	2002	618,816	255,557	614,311
	2004	623,851	279,952	557,453
Number of Patients receiving surgery (Y2)	1998	8153	4202	7541
	2002	10,003	5141	9170
	2004	10,234	5750	9345
Number of patient days (Y3)	1998	104,931	44,369	91,744
	2002	141,376	46,572	133,713
	2004	145,355	49,313	130,792
Number of net inpatient mortality (a)	1998	202	138	170
	2002	199	132	168
	2004	211	143	197

intensive care, and chronic care patient days; and (4) the number of net inpatient mortalities (a), which include mortalities occurring 48 hours after ambulatory procedures, but exclude emergency room mortalities, stillbirths, and early neonatal deaths.

The quality level, measured by the number of net inpatient mortalities, is an outcome healthcare quality indicator. The total

inpatient mortality is a critical and readily available indicator and exhibits several healthcare qualities. Therefore, the mortality rate is a concern not only for patients, but also for insurance companies, and the public health authorities. Note that rather than using the total inpatient mortality, we have only taken the mortality of ambulatory patients after 48 hours duration, and

Table 2

Individual hospitals' productivity change, quality change, relative efficiency change, and technical change.

Hospitals	Productivity change	Quality change	Relative efficiency change	Technical change
<i>Panel A: 1998–2002</i>				
1	0.9394	0.9345	1.0000	1.0052
2	0.7789	0.7711	1.0445	0.9671
3	0.8683	1.0000	1.0000	0.8683
4	0.6575	0.6428	1.0546	0.9698
5	0.8989	0.8433	1.0736	0.9929
6	0.4748	1.0000	0.8541	0.5559
7	0.6407	0.6363	0.9045	1.1131
8	0.6644	0.7022	1.0000	0.9462
9	0.9803	0.9996	0.9387	1.0447
10	0.4014	0.3976	0.9935	1.0161
11	0.6968	1.0081	0.7102	0.9732
12	0.7983	1.0000	1.0000	0.7983
13	0.9222	1.2018	0.8082	0.9495
14	0.5721	0.6358	1.0000	0.8998
15	0.9823	1.0093	0.9388	1.0367
16	0.6607	0.6920	1.0000	0.9548
17	1.0611	1.0000	0.9992	1.0620
18	0.4193	0.3864	1.0799	1.0050
19	0.9534	1.0000	0.9747	0.9782
20	1.1014	1.0000	1.0390	1.0601
21	0.5852	1.0000	1.0000	0.5852
22	0.6977	0.9593	0.7505	0.9691
23	0.8644	0.9798	1.0000	0.8822
24	1.6184	1.0000	1.0000	1.6184
25	0.3923	0.3697	1.0000	1.0610
26	0.7190	1.0000	1.0000	0.7190
27	0.6320	1.0000	1.0000	0.6320
28	1.1992	1.0000	1.0000	1.1992
29	0.9136	0.9841	1.0000	0.9284
30	0.5662	0.5878	1.0000	0.9632
31	0.7584	1.0592	0.9441	0.7584
<i>Panel B: 1998–2004</i>				
1	0.3144	0.2970	1.0000	1.0589
2	0.7396	0.7197	1.0000	1.0276
3	0.9676	0.8273	1.0997	1.0634
4	0.7378	0.6848	1.0919	0.9866
5	1.0951	1.0001	1.1096	0.9868
6	0.7550	1.0000	0.8541	0.8839
7	1.0718	1.0000	0.9186	1.1667
8	0.9971	1.0000	1.0000	0.9971
9	0.8426	1.0000	0.9387	0.8976
10	0.3563	0.5921	0.9935	0.6057
11	0.2875	0.5493	0.6425	0.8148
12	0.8730	1.0000	1.0000	0.8730
13	1.1710	1.2287	0.9843	0.9682
14	0.9113	1.0000	1.0000	0.9113
15	1.0164	1.0201	0.9967	0.9996
16	0.5565	0.6875	1.0000	0.8094
17	1.2770	1.0542	0.9486	1.2770
18	0.3781	0.3757	1.0145	0.9919
19	1.0156	1.0000	0.9747	1.0420
20	1.0188	1.0000	1.0412	0.9785
21	0.7027	1.0000	1.0000	0.7027
22	0.5306	0.6555	0.7654	1.0575
23	0.8484	0.9728	1.0000	0.8721
24	1.7976	1.0000	1.0000	1.7976
25	1.0187	1.0000	1.0000	1.0187
26	1.0047	1.0000	1.0386	0.9673
27	0.8165	1.0000	1.0000	0.8165
28	1.1176	1.0000	1.0000	1.1176
29	0.9166	0.9838	1.0000	0.9317
30	0.9762	1.0000	1.0000	0.9762
31	1.0086	1.0592	0.9441	1.0086

excluded emergency room mortality, stillbirths, and early neonatal deaths as the net inpatient mortality. However, the net inpatient mortality number is identified as bad (undesirable) output. If we treat the output as input, the resulting DEA model does not reflect the true production process. We thus adopt Seiford and Zhu [54] that multiplied each bad output by “-1” and apply a proper translation vector to let all negative bad output be positive. After linear monotone decreasing transformation, the inputs and outputs fit the isotony and convexity relations in DEA application.

4. Empirical results

4.1. Descriptive statistics

Table 1 provides descriptive statistics for hospital inputs and outputs for the pre-TQIP period (1998) and post-TQIP period (2002 and 2004). The means of inputs and outputs all increased from pre-TQIP period to post-TQIP period. The number of net inpatient mortality (a) is identified as bad (undesirable) output. The healthcare quality improves as the number of net inpatient mortality decreases relative to the other desirable output increases. In the pre-TQIP period (1998), the rates of the number of net inpatient mortality divided by the desirable output (number of outpatient visits, number of patients receiving surgery, or number of patient days) are 0.044%, 2.48%, and 0.193%. In the post-TQIP period (2002 and 2004), the average rates decrease to 0.033%, 1.10%, and 0.143%. These results demonstrate healthcare quality improvement.

4.2. Quality change and efficiency change

4.2.1. Individual hospital productivity change

Table 2 reports individual hospitals' productivity change, quality change, relative efficiency change, and technical change from the pre-TQIP period (1998) to the post-TQIP period (2002

and 2004). Table 3 shows the frequency distribution of the Malmquist productivity index and other component factors contributing to the overall productivity change. From Panel A of both Tables 2 and 3, we observe that the average quality grows by 13.55% ($=1-0.8645=0.1355$) from the pre-TQIP period to the post-TQIP period (1998–2002) and only 4 hospitals' quality deteriorate. The average relative efficiency improves by 2.88% ($=1-0.9712=0.0288$) and 5 hospitals' relative efficiency regress. The average technical change increases by 4.80% ($=1-0.9520=0.0480$) and there are 20 hospitals showing progress in technical performance. The quality growth, relative efficiency improvement, and technical progress contribute to 21.23% ($=1-0.7877=0.2123$) increase in productivity from 1998–2002. Among the productivity changes, the most important trigger derives from the quality progress (13.55%).

The results from Panel B of both Tables 2 and 3 reveal the hospital productivity change, quality change, relative efficiency change, and technical change from pre-TQIP period (1998) to post-TQIP period (2004). The productivity improvement is 12.52% composed of the quality improved (10.62%), relative efficiency progressed (2.08%), and technical promoted (1.27%). Therefore, the overall improvement in productivity change, quality change, and relative efficiency change from 1998 to 2004 is lower compared to the progress in productivity change, quality change, and relative efficiency change from 1998 to 2002. This was attributable to the severe SARS impact in 2003. In 2003, SARS resulted in 346 contagions and 73 dead and had a serious impact on healthcare and economics of Taiwan. The public was reluctant to seek medical aids from hospitals until 2004.

4.2.2. Overall hospital productivity change

Table 4 summarizes the statistics of the productivity change index and its components from the pre-TQIP period to the post-TQIP period (1998–2002 and 1998–2004). To evaluate our hypotheses, we test the Malmquist productivity index and its components for 1998–2002 and 1998–2004. We find that both

Table 3
Distribution of the Malmquist productivity index, quality change, relative efficiency change, and technical change.

Productivity index	Productivity change	Quality change	Relative efficiency change	Technical change
<i>Panel A: 1998–2002</i>				
< 0.5	4	3	0	1
0.5 < = < 0.6	3	1	0	2
0.6 < = < 0.7	7	4	0	1
0.7 < = < 0.8	4	2	2	3
0.8 < = < 0.9	3	1	2	3
0.9 < = < = 1.0	6	16	22	11
1.0 < < 1.1	1	3	5	8
1.1 < =	3	1	0	3
Mean	0.7877	0.8645	0.9712	0.9520
Median	0.7584	0.9996	1.0000	0.9691
CV (%)	32.85	25.35	8.76	20.30
<i>Panel B: 1998–2004</i>				
< 0.5	4	2	0	0
0.5 < = < 0.6	2	2	0	0
0.6 < = < 0.7	0	3	1	1
0.7 < = < 0.8	4	1	1	1
0.8 < = < 0.9	4	1	1	7
0.9 < = < = 1.0	5	17	22	11
1.0 < < 1.1	8	4	5	7
1.1 < =	4	1	1	4
Mean	0.8748	0.8938	0.9792	0.9873
Median	0.9165	1.0000	1.0000	0.9866
CV (%)	35.42	24.06	9.16	20.12

The Malmquist productivity index is calculated based on equation (4). CV is the coefficient of variation.

Table 4

Tests of productivity change, quality change, efficiency change, and technical change from pre-TQIP period to post-TQIP period (1998–2002 and 1998–2004).

Variables and predicted signs	Period from-to	Mean	<i>p</i> -value for <i>T</i> -test for mean=1 ^a	Median	<i>p</i> -value for sign test for median=1 ^a	<i>p</i> -value for sign rank test for median=1 ^a
Productivity change	1998–2002	0.7877***	0.00	0.7584***	0.00	0.00
	1998–2004	0.8748***	0.00	0.9166***	0.14	0.00
Quality change	1998–2002	0.8645***	0.00	0.9996***	0.00	0.00
	1998–2004	0.8938***	0.00	1.0000*	0.10	0.00
Relative efficiency change	1998–2002	0.9712**	0.03	1.0000*	0.10	0.05
	1998–2004	0.9792**	0.04	1.0000	0.16	0.16
Technical change	1998–2002	0.9520**	0.04	0.9691*	0.07	0.03
	1998–2004	0.9873	0.18	0.9866*	0.07	0.10

^a The *p* values are for testing whether productivity or quality change or relative efficiency change or technical change is significantly less than one. *Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level for one-sided hypothesis tests.

the means of the quality change and relative efficiency change index are significantly less than one for the period of 1998–2002 (0.8645, 0.9712) and 1998–2004 (0.8938, 0.9792), indicating that TQIP hospitals improved their quality and efficiency in the post-TQIP period. In addition, the aggregate effects from the quality and efficiency progress have led to productivity growth after the TQIP adoption (0.7877, 0.8748). These evidence support *H1*, *H2* and *H3*. That is, after joining TQIP, hospitals can identify the non-value-added process and reduce cost as well as thorough cost structure comprehension.

4.3. Discussions

The quality and efficiency of the hospitals are two of the major concerns to patients when they seek healthcare services. Hospitals have to enhance their healthcare quality and efficiency in order to attract new patients and retain existing patients. After joining TQIP, hospitals are able to identify the non-value-added processes, reduce costs, discover quality problems, comprehend the in-house quality status quo, improve data collection methods, and promote the quality philosophy. As a result, these hospitals should have improved their service quality and efficiency after TQIP participation.

While the healthcare quality is not cost free, our empirical results indicate that the quality and efficiency improvements can be achieved simultaneously without a tradeoff. That is, after joining TQIP, hospitals are able to collect and utilize the acute care indicators which, in turn, facilitate improvements in healthcare quality and efficiency. The result of simultaneous improvement in both quality and efficiency not only coincides with the philosophy of total quality management spirit, but also confirms the efficiency enhancement and quality assurance functions of TQIP.

Our study is based on the policy intervention derived from the TQIP participation. Prior research had examined factors affecting healthcare efficiency and/or quality, including (a) hospital operating characteristics, such as hospital ownership [19,20,55,56], length of stay [57–59], new medical technology [59–61], financial structure [59,62], market competition [63–65], teaching mission [66,67] and (b) case-mix differences [19,20] such as illness severity [68], degree of specialization [69,70], and aging population [71,72]. Hospitals need to collect data on these factors and incorporate them into documentary indicators so that hospitals can continuously enhance their healthcare quality and efficiency through improvements in these indicators.

5. Conclusion

The goal of TQIP is to promote overall healthcare quality. In this study, we empirically evaluate the impact of TQIP adoption on hospital productivity and healthcare quality. Using the empirical data on 31 TQIP regional hospitals in Taiwan over the periods 1998–2004, we examine the impact of TQIP on productivity change, quality change, and relative efficiency change. In particular, we analyze the changes in efficiency and quality derived from the Malmquist productivity change index. Our results indicate that hospitals had improved their healthcare quality, efficiency, and total productivity from the pre-TQIP period (1998) to the post-TQIP implementation period (2002 and 2004). Efficiency and quality improve concurrently after TQIP participation, which coincides with the philosophy of TQM. That is, hospitals are able to improve their operating efficiency without sacrificing their healthcare quality.

Our study results have the following policy and managerial implications. First, the mission of healthcare is to promote the healthcare quality. Our study assures that quality indicator systems facilitate the continuous improvement of healthcare quality. Second, our findings suggest that healthcare quality and efficiency can be achieved simultaneously. The advancement in healthcare quality would lead to improvements in healthcare productivity and quality improvement as well. Third, the healthcare quality progress requires transformation of time and input resources.

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References

- [1] Cosmetatos GP, Eilon S. Effects of productivity definition and measurement on performance evaluation. *European Journal of Operational Research* 1983;14:31–5.
- [2] Walker KB, Dunn LM. Improving hospital performance and productivity with the balanced scorecard. *Academy of Health Care Management Journal* 2006;2:85–110.
- [3] Shimshak DG, Lenard ML, Klimberg RK. Incorporating quality into data envelopment analysis of nursing home performance: a case study. *Omega* 2009;37:672–85.
- [4] Rosenstein A. Health economics and resource management: a model for hospital efficiency. *Hospital and Health Services Administration* 1991;36:313–30.

- [5] Maniadakis N, Hollingsworth B, Thanassoulis E. The impact of the internal market on hospital efficiency, productivity and service quality. *Health Care Management Science* 1999;2:75–85.
- [6] Collins KF, Muthusamy SK. Applying the Toyota production system to a healthcare organization: a case study on a rural community healthcare provider. *Quality Management Journal* 2007;14:41–52.
- [7] Thielst CB, Gardner JH. Clinical documentation systems: another link between technology and quality. *Journal of Healthcare Management* 2008;53:5–7.
- [8] Syam SS, Cote ML. A location-allocation model for service providers with application to not-for-profit health care organizations. *Omega* 2010;38:157–66.
- [9] Watcharasriroj B, Tang TJ. The effects of size and information technology on hospital efficiency. *Journal of High Technology Management Research* 2004;15:1–16.
- [10] Natarajan RN. Transferring best practices to healthcare: opportunities and challenges. *TQM Magazine* 2006;18:572–82.
- [11] Shortell SM, Bennett CL. Assessing the impact of continuous quality improvement on clinical practice. What it will take to accelerate progress. *Milbank Quarterly* 1998;76:625–48.
- [12] Bosworth D, Massini S, Nakayama M. Quality change and productivity improvement in the Japanese economy. *Japan and the World Economy* 2005;17:1–23.
- [13] TJCHA. The proceedings of the second anniversary of Taiwan Quality Indicators Project (TQIP) Meeting, Taiwan Joint Commission on Hospital Accreditation, 2001.
- [14] Malmquist S. Index numbers and indifference surfaces. *Trabajos de Estadística* 1953;4:209–42.
- [15] Banker RD, Conrad R, Strauss R. A comparative application of data envelopment analysis and translog methods: an illustrative study of hospital production. *Management Science* 1986;32:31–44.
- [16] Pilyavsky AI, Aaronson WE, Bernet PM, Rosko MD. East-west: does it make a difference to hospital efficiencies in Ukraine? *Health Economics* 2006;15:1173–92.
- [17] Sola M, Prior D. Measuring productivity and quality changes using data envelopment analysis: an application to Catalan hospital. *Financial Accountability and Management* 2001;17:219–45.
- [18] Färe R, Grosskopf S, Roos P. Productivity and quality changes in Swedish pharmacies. *International Journal of Production Economics* 1995;39:137–47.
- [19] Chang H, Chang WJ, Das S, Li SH. Health care regulation and the operating efficiency of hospitals: evidence from Taiwan. *Journal of Accounting and Public Policy* 2004;23:483–510.
- [20] Chang H, Cheng M, Das S. Hospital ownership and operating efficiency: evidence from Taiwan. *European Journal of Operational Research* 2004;159:513–27.
- [21] Donabedian A. Evaluating the quality of medical care. *The Milbank Quarterly* 2005;83:691–730.
- [22] Donabedian A. Explorations in quality assessment and monitoring, volume 1. *The Definition of Quality and Approaches to Its Assessment*. Michigan, Health Administration Press 1980;86.
- [23] Landon BE, Epstein AM. For-profit and not-for-profit health plans participating in Medicaid. *Health Affairs* 2001;20:162–71.
- [24] Alexander J, Weiner B, Griffith J. Quality improvement and hospital financial performance. *Journal of Organizational Behavior* 2006;27:1003–29.
- [25] Bull A. Specifying quality in health care. *Journal of Management in Medicine* 1994;8:5–8.
- [26] Kanji GK, Sa PM. Sustaining healthcare excellence through performance measurement. *Total Quality Management and Business Excellence* 2003;14:269–85.
- [27] Longest BB. An empirical analysis of the quality/cost relationship. *Hospital and Health Services Administration* 1978;20:35.
- [28] Fleming ST. The relationship between quality and cost: pure and simple? *Inquiry* 1991;28:29–38.
- [29] Cleverley WO, Harvey RK. Is there a link between hospital profit and quality? *Healthcare Financial Management* 1992;9:40–5.
- [30] Harkey J, Vraciu R. The improving efficiency of university health consortium hospitals. *Journal of Public Budgeting, Accounting, and Financial Management* 1992;19:385–99.
- [31] Caves D, Christensen L, Diewert, WE. The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica* 1982;50:1393–414.
- [32] Caves D, Christensen L, Diewert, WE. Multilateral comparisons of output, input, and productivity using superlative index numbers. *Economic Journal* 1982;92:73–86.
- [33] Althin R, Färe R, Grosskopf S. Profitability and productivity changes: an application to Swedish pharmacies. *Annals of Operations Research* 1996;66:219–30.
- [34] Färe R, Grosskopf S, Lindgren B, Poullier JP. Productivity growth in health care delivery. *Medical Care* 1997;35:354–66.
- [35] Tambour M. The impact of health care policy initiatives on productivity. *Health Economics* 1997;6:57–70.
- [36] Margit SR. The impact of the Austrian hospital financing reform on hospital productivity: empirical evidence on efficiency and technology changes using a non-parametric input-based Malmquist approach. *Health Care Management Science* 2000;3:309–21.
- [37] Miika L. Health care financing reform and the productivity change in Finnish hospitals. *Journal of Health Care Finance* 2000;26:83–100.
- [38] Prior D. Efficiency and total quality management in health care organizations: a dynamic frontier approach. *Annals of Operations Research* 2006;145:281–99.
- [39] Aktas E, Ullengin F, Sahin SO. A decision support system to improve the efficiency of resource allocation in healthcare management. *Socio-Economic Planning Sciences* 2007;41:130–46.
- [40] Hendriks HJM, Bekkering GE, Ettekooven H, Brandsma JW, Wees PJ, Bie RA. Development and implementation of national practice guidelines: a prospect for continuous quality improvement in physiotherapy. *Physiotherapy* 2000;86:535–47.
- [41] Färe R, Grosskopf S, Lindgren B, Roos P. Productivity changes in Swedish pharmacies 1980–1989: a non-parametric Malmquist approach. *Journal of Productivity Analysis* 1992;3:85–101.
- [42] Maniadakis N, Thanassoulis E. A cost Malmquist productivity index. *European Journal of Operational Research* 2004;154:396–409.
- [43] Zelenyuk V. Aggregation of Malmquist productivity indexes. *European Journal of Operational Research* 2006;174:1076–86.
- [44] Fiordelisi F, Molyneux P. Total factor productivity and shareholder returns in banking. *Omega* 2010;38(5).
- [45] Chang H, Choy H, Cooper W, Ruefli T. Using Malmquist Indexes to measure change in the productivity and efficiency of US accounting firms before and after the Sarbanes–Oxley Act. *Omega* 2009;37:951–60.
- [46] Kao C. Malmquist productivity index based on common-weights DEA: the case of Taiwan forests after reorganization. *Omega* 2010;38(6).
- [47] Shephard RW. *Theory of cost and production functions*. Princeton: Princeton University Press; 1970.
- [48] Cook WD, Seiford LM, Zhu J. Models for performance benchmarking: measuring the effect of e-business activities on banking performance. *Omega* 2004;32:313–22.
- [49] Du J, Liang L, Chen Y, Bi G. DEA-based production planning. *Omega* 2010;38:105–12.
- [50] Bounol M, Dula JH, Lins MPE, Moreira da Silva AC. Enhancing standard performance practices with DEA. *Omega* 2010;38:33–5.
- [51] Banker RD, Chang H, Natarajan R. Productivity change, technical progress, and relative efficiency change in the public accounting industry. *Management Science* 2005;51:291–304.
- [52] Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science* 1984;30:1078–92.
- [53] Banker RD, Das S, Datar S. Analysis of cost variances for management control in hospitals. *Research in Governmental and Nonprofit Accounting* 1989;5:269–91.
- [54] Seiford LM, Zhu J. Modeling undesirable factors in efficiency evaluation. *European Journal of Operational Research* 2002;142:16–20.
- [55] Duggan M. Hospital ownership and public medical spending. *Quarterly Journal of Economics* 2000;114:1343–73.
- [56] Sloan FA, Picone GA, Taylor GA, Chou SY. Hospital ownership and cost and quality of care: is there dime's worth of difference? *Journal of Health Economics* 2001;20:1–21.
- [57] Martin S, Smith P. Explaining variations in inpatient length of stay in the National Health Service. *Journal of Health Economics* 1996;15:279–304.
- [58] Younis M, Rivers PA, Fottler MD. The impact of HMO and hospital competition on hospital costs. *Journal of Healthcare Finance* 2004;31:60–74.
- [59] Hung JH, Li Chang. Has cost containment after the National Health Insurance system been successful? Determinants of Taiwan hospital costs *Health Policy* 2008;85:321–35.
- [60] Cutler D, McClellan M. Is technological change in medicine worth it? *Health Affairs* 2001;20:11–29.
- [61] Hay J. Hospital cost drivers: an evaluation of 1998–2001 state-level data. *American Journal of Managed Care* 2003;9:14–24.
- [62] Oszustowicz RJ. Quality of care emerges as a determinant of creditworthiness. *Healthcare Financial Management* 1992;46:48–53.
- [63] Melnick G, Zwanziger J. Hospital behavior under competition and cost-containment policies: the California experience. *Journal of the American Medical Association* 1988;260:2669–75.
- [64] Nyman J, Bricker D. Profit incentives and technical efficiency in the production of nursing home care. *Review of Economics and Statistics* 1989;71:586–94.
- [65] Fazel JL, Nunnikhoven TS. The efficiency of nursing home chains. *Applied Economics* 1993;25:49–55.
- [66] Rich E, Gifford G, Luxenberg N, Dowd B. The relationship of house staff experience to the cost and quality of inpatient care. *Journal of the American Medical Association* 1990;263:953–7.
- [67] Feinglass J, Schroder J, Martin G, Wallace W, Lyons J. The relationship of residents' autonomy and use of a teaching hospital's resource. *Academic Medicine* 1991;66:549–52.
- [68] Thorpe K, Florence S, Joski P. Which medical conditions account for the rise in healthcare spending? *Health Affairs* 2004;437–45.
- [69] Farley D, Hogan C. Case-mix specialization in the market for hospital services. *Health Services Research* 1990;26:757–83.
- [70] Chang H. Determinants of hospital efficiency: the case of central government-owned hospitals in Taiwan. *Omega* 1998;26:307–17.
- [71] Goetghebuer M, Forrest S, Hay J. Understanding the underlying drivers of patient cost growth: a literature review. *The American Journal of Managed Care* 2003;9:3–12.
- [72] Seshamani M, Gray AM. A longitudinal study of the effects of age and time to death on hospital costs. *Journal of Health Economics* 2004;23:217–35.