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by

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1. Introduction

In order to understand the production and provision of hospital services it is useful to consider in what respect hospital services, or health care services in general, differ from other commodities. Weisbrod (1991, p.524) put forward that these commodities in many cases involve the preservation of life, or, at least have major effects on the quality of life, and by so significantly differ from many other commodities. The provision and financing of many hospital services also differ. In many countries' public or nonprofit provided care dominates over private for profit institutions. Public provided health care are conventionally explained by the fact that individuals in many cases are not able to make well- informed judgments about the quality of care, see Weisbrod (1991, p.525). The state of medical technology, characteristics of producers, way of financing, and information of how these commodities are expected to effect life, and in particular, the quality of life, are all important in understanding the tripled of expenditures on these services witnessed during the last decades, and in particular, the measurement of output and productivity.

In the literature, one can find little disagreement on the importance of having a definition of hospital output that focus on changes or maintaining of individual's health status and quality of life, see, e.g., Zweifel and Breyer (1995) for a summary and discussion of this subject. However, in empirical studies variables as, e.g., beddays, treated patients, discharges etc., are used as proxies for hospital output. These types of proxies are, however, inappropriate because they measure the means to real output rather than output itself. For example in evaluation of productivity, changes in the technology will affect input use as well as characteristics of the output. In the latter case very often in terms of changes in characteristics related to what patients and doctors think of as quality aspects which will not be captured in above mentioned types of proxies. Above proxies can only be used if output do not changes and productivity capture changes in inputs due to changes in the organization hospital activities.

In this paper an alternative approach is suggested for the measurement of hospital output and for the measurement of productivity changes. The conceptual framework included in the measurement of hospital output take as a starting point the effects for the patient in terms of changes in health status and changes in basic daily life activities. This framework originate from work by Professor Armatya Sen on well- being, and in particular from Sen's concept functionings and capabilities. The purpose also include presentation of Malmquist productivity indexes as an suggestion for the measurement of productivty. Malmquist productivity index approaches has prove very to be very useful in situations with many inputs and many outputs, and where price information is missing or inappropiate, e.g., in many service sectors. The index approaches here suggested originate from earlier work by Malmquist (1953), Caves, Christenson and Diewert (1982), and Färe, Grosskopf and Roos (1995). In order to show how the approaches can be used in an empirical application the index approaches is illustrated in the case of eye surgery. The illustration to cataract surgery shows that hospital output may be under estimated if we use proxies like number of treatment or deddays instead of effects on individuals living conditions. In the case of cataract surgery, the illustration indicates that output could be 30-40 per cent higher per treatment when we compare 1980 with 1996.

The illustration to cataract surgery shows how productivity can be measured when we also would like to take into account changes in living conditions and quality aspects as changes in the risk for complications from surgery. The illustration indicates that our measure of productivity changes may be very misleading if we do not take into account changes effects on living or quality aspects due to improvements in medical technology.

2. An index approach for the measurement of hospital output

An issue of growing interest among health care policy makers is to measure changes in health status and changes in quality of life, and in particular, changes as an indicator of hospital output. Today the evaluation of such changes has become a multidisciplinary field including philosophy, medicine, psychology and economics. Quality of life is a difficult term to define and the definition may be different across fields. In this study we focus on how quality of life in terms of *daily living activities* are affected by a disease or injury and by treatment. The limitation to changes in health is some times called health related quality of life, see, e.g., Patrick and Ericsson (1992), Brock (1993), and Brooks (1995) for a discussion of the concepts of health status and quality of life in health care and for a presentation of methods of measurement.

Independent of discipline the methods suggested in the literature very often have a problem with providing a single overall score, i.e., an index number, showing the change in health status or quality of life. In many of these studies different aspects of health status and quality of life are presented as independent dimensions, or as profiles, and very often unit of measurement differ across the variables. Problems arises in the summation of variables due to differences in unit of measurement or to difficulties in setting weights. Another drawback is that a priori fixed weights are used to summarize statements of activities or aspects of health status into an overall index number. The measure may be sensitive to the weights allot to different components of the index. This is because the weights set by, e.g., an expert panel, reflects the average weights, and we may have great differences between experts as well as between experts and individuals. Individuals may very well differ with respect to the relative valuation of activities, because of different lives. If so, one would expect individuals to differ in levels of activities, even if we are talking about daily life activities. Of course, individuals may have the opportunity to choose the same activities, but they may choose differently. Furthermore, a disease or injury may affect individuals in different ways. The methods using fixed average weights do not allow us to capture such differences in choices.

The purpose with index numbers is to summarize all the information we have on, e.g., activities and on health status, in order be able to compare the situation of an individual before and after surgery, and by to be able to have a measure of hospital output. The index approach should be able to compare output over time, i.e., an index measuring differences between the output from old hospital technology with the output of a new. A problem is to find index formulas and to calculate the index numbers. The index formula gives us the principals for the calculation, and hence which properties the indexes satisfy. The index number, the scalar value, is the result from the calculation. The purpose of this paper is to illustrate a recently developed index method for the measurement of changes in output of hospital services, Roos and Björk (1992), Björk and Roos (1994) and Lundström and Roos (1995). The method is based on so called Malmquist quantity index. Malmquist quantity index does not require a priori fixed weights in the summation of activities and it has the property of making the index also depending on clinical data measuring the health status of an individual. The distinction between health status and quality of life in terms of daily life activities is important for our index approach. Health status consists of dimensions which can be seen as inputs for the individual, and are important factors in determining the limits for activities possible to achieve by the individual. A reduction in all or some health dimensions, will restrict the set of attainable activities. Activities can in a similar way be seen as outputs for the individual.

2.1 A Malmquist index approach measuring quantity changes in output

The Malmquist index approach for the measurement of hospital output consists of two steps. The first steps give us a conceptual framework for modeling the set of activities available to an individual. Given the conceptual framework the index formula is constructed. In the second step the components of the index is calculated using linear programming technique.

The index approach out lined below is limited to case with a clear start and end of hospital service. For example, the treatment of hip- joint replacement and cataract surgery have a clear start and end, and hospital product can be specified using two dates, i.e., before and after treatment. The approach presented *does not deal with* cases when hospital output has to be specified using long time interval as, e.g., when treatment is to maintain health or slow down the progress of a disease.

The conceptual framework in this type of Malmquist quantity index brings out the production aspect of health of the individual, see Grossman (1972), Muurinen (1982) and Zweifel and Breyer (1995). The health production framework has earlier been used in studies of, e.g., demand for health, see, e.g., Wagstaff (1986) and Häkkinen (1991).

A disease or injury will set restrictions on what a person will be able to do. From investment in health the possibilities of achieving personal goals in terms of what he/she manages to do or to be may change, i.e., the restrictions that an individual face may change. The idea of focusing on an individual in terms of activities, or functioning's, is closely related to the ideas presented by Professor Amartya Sen (1985,1993). In Sen's terminology a functioning reflects an achievement of a person in the way he/she manages "to do" or "to be", given a stock of commodities that he/she is in possession of and given his/her ability to transform the commodities into functioning. The commodities we think of as the persons input vector. In the index method suggested in this paper, we include health status as a part of the input vector that a person is in possession of. The reason for this is that we think of health status as being an input of choice for a person. For example, an individual may or may not demand an investment in a new hip-joint or cataract extraction, due to, e.g., expectations on how an investment will change his/her ability to perform activities.

Let x_i^0 be a vector of all inputs that an individual i is in possession of at date 0, which also includes health dimensions, e.g., binocular visual acuity, binocular reading ability, walking ability. The input vector of a person gives the requirements for different types living. For example, eye surgery may (will) increase the person's health in terms of visual acuity, and by so increase the 'size' of the input vector, and as a result change his/her ability to perform daily life activities. The change in the input vector may be restricted by a variety of factors. Some factors are related to the person others to the society. More important, some factors are a matter of choice for the individual and some are not. Examples of the latter are, other diseases, aging and access to health care and to medical technology.

Let b_i^0 be a vector of activities for individual i at date 0. The activities give us a description of a person's way of living. Given a person's x_i^0 vector we may think of many possible combinations of activities which all are feasible to achieve, i.e., different ways of living. What we observe is only one out of many possible ways of living. This mean that we have a set of feasible activity vectors, and individuals may choose differently, even in the case of daily life activities. The set has an important property in indicating the choice a person have given his/her inputs and how he/she succeed to transform inputs into activities. The set may be very different depending on the 'size' of x_i^0. Reduced health due to an disease or injury will (may) effect the set of available activity vectors. The result of an improvement in x can be measured as changes or no changes in activities. The changes in way of living will be dependent on the 'size' of x_i^0 and the restrictions that the person face, and may be very different across persons. So, both inputs and activities will be endogenous in this method.

Summing up. The notation of an individual at date 0, e.g., the situation before treatment, follows Sen (1985) but with and extension to health and limitation to basic daily life activities. The transformation is here expressed in terms of distance (output) functions.

x_i^0 = a vector of inputs, including health status, chosen by individual i at date 0.

X_i^0 = the set of all input vectors from which person i choose one at date 0, i.e., x_i^0 belong to X_i^0. A disease or injury will set restrictions on the set X_i^0.

b_i^0 = a vector of daily life activities achieved by person i at date 0 from a given vector of inputs and the transformation function.

$D_i^0\left(x_i^0, b_i^0\right)$ = the distance function of person i at date 0, showing the transformation of inputs into daily life activities. It model the transformation in terms of activity isoquants. It takes a value equal to 1 for all points located at the activity isoquant, a value less than 1 for point below the isoquant and a value greater than 1 for point not belonging to the set at date 0.

D_i^0 = the set of distance functions from which the person can choose one function at date 0.

$P_i^0\left(x_i^0\right) = \left[b_i^0 : D_i^0\left(x_i^0, b_i^0\right) \leq 1\right]$ = the set of all activity vectors feasible for the individual i at date 0 for a given input vector and for some distance function belonging to the set of feasible distance functions

$Q_i^0\left(X_i^0, D_i^0\right) = \left[b_i^0 : D_i^0\left(x_i^0, b_i^0\right) \leq 1\right]$ = the set of all activity vectors available to the individual i at date 0 for some distance function belonging to the set of feasible functions, D_i^0, and for some input vector belonging to the restricted set of input vectors, X_i^0, from which the individual can choose. Sen calls this set the 'capabilities' of a person i. "It reflects the various combinations of functioning's ('beings') he can achieve", Sen (1985, p.14). In this study we call functioning's for activities and limit the focus to daily life activities.

The purpose is to have an index of hospital output for patients with a similar disease or injury and which can be specified with a short time interval. A disease or injury may create a fall in

X_i^0 or D_i^0 and some b vectors may be non- feasible. On the other hand a treatment may have a positive effect on X_i^0 or D_i^0 and the set of feasible b-vectors may expand and the activity level of a person may increase. Of course, it may be impossible to observe all input and all activity vectors available for the person at a specific date.

2.2 Calculation of the output index

In this study we assume that the set of available activity vectors for person i can be modeled from observations on health related inputs and daily life activities from a sample of individuals all undergoing a specific treatment. We model the activity sets using a piecewise linear sets, or activity analysis model. In this analysis the set for each individual is constructed from empirical observations on inputs and activities from all individuals in the sample. The principle is that what we can observe from direct observations must have been possible since we can observe it. Other feasible combinations of activities, which can not be directly observed, are derived as convex combinations of observations.

The input vectors include variables on health status, e.g., variables on visual acuity, physical mobility, blood pressure etc. The input vector may also include other variables, not directly related to medical indicators, but related to health. We have i=1,2,, I, individuals, *n*= 1,2,...N inputs and *m*=1,2,....M activities at time 0. In this case the set of activity vectors is formed from observations as

(2.1)

$$P^0\left(x^0\right)=\left\{b^0: b_m^0 \leq \sum_i^I z^{i,0} b_m^{i,0}, m=1,2\ldots M, x_n^0 \geq \sum_i^I z^{i,0} x_n^{i,0}, n=1,2\ldots N, z^{i,0} \geq 0, i=1,2\ldots I\right\}$$

The intensity variables, $z^{i,0}$, are used in order to model the transformation technology as convex combinations of inputs and activities. Different scaling properties of inputs and activities can be imposed by restricting the sum the intensity variables.

Values to the distance function $D^0\left(x^{i,0}, b^{i,0}\right)$ can be calculated as solution to the following linear programming problem

(2.2)

$$\left[D^o\left(x^{i,o}, b^{i,o}\right)\right]^{-1} = max\, \lambda$$

subject to

$$\lambda b_m^{i,0} \leq \sum_i^I z^{i,0} b_m^{i,0}, m=1,2\ldots M, x_n^{i,0} \geq \sum_i^I z^{i,0} x_n^{i,0}, n=1,2\ldots N, z^{i,0} \geq 0, i=1,2\ldots I$$

In order to have a measure of hospital output we also need to calculate a value to $D^0\left(x^{i,0}, b^{i,1}\right)$. In this case we may have an activity vector from date 1, i.e. after treatment, outside the activity set modeled at date 0. A value to $D^0\left(x^{i,0}, b^{i,1}\right)$ is calculated for individual i as the solution to the following linear programming problem to

(2.3)

$$\left[D^o\left(x^{i,o}, b^{i,1}\right)\right]^{-1} = max\,\lambda$$

subject to

$$\lambda b_m^{i,1} \leq \sum_i^I z^{i,0} b_m^{i,0}, m = 1,2\ldots M, x_n^{i,0} \geq \sum_i^I z^{i,0} x_n^{i,0}, n = 1,2\ldots N, z^{i,0} \geq 0, i = 1,2\ldots I$$

Given values to we are able to calculate the index measuring changes in daily life activities or hospital output as

(2.4)

$$I = D^0(x^0, y^1) / D^0(x^0, y^0)$$

for individual i. The result may differ across individuals. As a measure of total hospital output one may simply summarize all changes, for all individuals or for subgroups of individuals. Subgroups may be considered if individuals. In the latter case one may think of the situation when the patient differ in respect to other diseases.

The index approach is illustrated in Figure 2.1 for a given input vector before treatment and two activities (b_1 and b_2). In Figure 2.1 the set of attainable activity vectors before treatment, i.e., at date 0, is bounded by the curve a,A,B,d. It contains all combinations of b_1 and b_2 on and below this curve. We notice that the sets include vectors with zero in one activity as well as the theoretical possibility of having a level of zero in all activities, i.e., origin is included in the set of activities. Since we are focusing on ways of living in terms of *attainable activities* all points on the curve a,A,B,d must be equal as regards level of overall activity, i.e., we do not distinguish between points in terms of value to the individual. These mean that the summation of activities should have an index number of 1 for all points located at the curve. For points below the curve we should have an index number less than 1, e.g., point C. By definition, the distance function takes a value equal to 1 for points at the curve. So for A and B the denominator in the index in (2.4) takes a value of 1. For C the distance function takes a value less than 1 and it is calculated as the ratio between the distance from origin to C and the distance from origin to D, i.e., 0C/0D<1 in Figure 2.1. The point D is located at the curve, and it is reach by an radial expansion of C.

The conceptual framework allows for the possibility that an individual does not reach highest possible activity level. For example, individual C is located below the isoquant. We can think of many reasons for why not C reaches a higher activity level. Examples can be restrictions not controlled by the variables included in the index. Why C differs in this respect may be of great interest, but it is not important for the construction of the index.

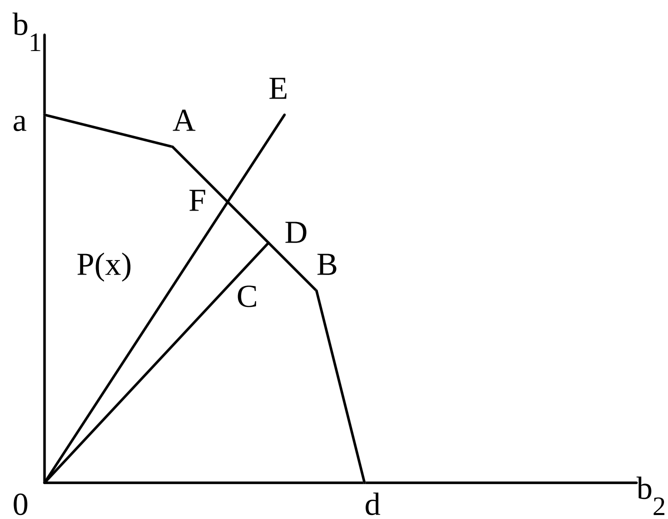

Figure 2.1. Illustration of activities before surgery and changes in activities due to treatment

Observations above the curve a,A,B,d, e.g., point E in Figure 2.1, is not possible given the input vector of health status before treatment. As a result of treatment health status increase and point E is now available for the person. Hospital output is a measure of changes in activities and the situation after treatment is compared with the situation before. In Figure 2.1 we are now looking for an index number at point E. This point is above the curve and the index number should be larger than 1 when we use the situation before treatment as a reference. The numerator in the index (I) for individual C, i.e., the value to the distance function in this point, is calculated as the ratio between the distance from origin to E and the distance from origin to the point F at the reference curve, i.e., 0E/0F >1 in Figure 2.1. At the point F the distance function takes a value equal to 1.

In an empirical investigation we very often have many inputs of health status and many activities. The methods do not set any restrictions in the number of inputs and activities. Some variables can vary often be easily and objectively measured, e.g., clinical variables on health status. For other variables the measurement and scale may be more difficult to define. An alternative can be to instead use information that provides a characterization of the variable, i.e., convert the variable into two or several characteristic variables. In terms of measurement of variables the method allows for the unit of measurement to vary across variables, i.e., the unit of measurement is not required to be the same among inputs or among activities. Another alternative may be to use variables from questionnaires focusing on profile of individuals living conditions.

We also like to compare hospital output over time. Over time medical technology may change, i.e., the way of treatment change. As a result of a new way of treatment the hospital may be able to increase the effect on health status. However, this may or may not affect daily life activities. In order to have a measure of hospital output we calculate the index in (2.4) for individuals undergoing a treatment for a similar disease or injury at time period 0, i.e., the old medical technology, and at time period 1, i.e., the new medical technology. In both time periods we use the distance function modeling the individuals' activity sets from the later period as a reference.

In order to have a measure of hospital, department, output of a treatment of a disease or injury one can think of different alternatives. One alternative could be to calculate the total output as the a summation of individual index score at each time period. Another alternative is to use the average of individual index scores together with total number of treatment as a measure of output.

The index approach suggested above does not take into individuals' valuations of activities. This should not, we think, be seen as a drawback of the index approach. Instead it should be seen as an approach focusing on factors behind a valuation of changes in well- being, or quality of life. It can be seen as a primary specification of well- being, Sen (1985, p. 51) an measured as an index of changes in functionings. In this case changes in daily life activities which takes into account restrictions on health status. This we think is an advantage with the approach. However, if we have valuations, or the importance, of activities or changes in activities, we may be able to distinguish between different point at the curve a,A,B,d or between different movements in Figure 2.1. For example, only points at the curve which are able to create a certain overall *value* for the person will have an index of 1. The index may in the future be extended to include relative valuations.

2.3 An illustration to cataract surgery

Today there exists no medical cure of the cataract itself. In order to increase the visual acuity for the individual the lens has to be extracted. The technique to remove the lens has developed over time. It started with the ancient Greeks. They pushed it back into the body of the eye. The risk for complications must have been very high and the procedure very painful. During the last 100 years we have had developments in extraction of the lens out of the eye. Since the last decades the extraction of the lens is regarded as a relatively safe operation. Today we have a very low risk for complications.

After the extraction of the lens the visual acuity has improved because the opacities in the lens is not more a problem. However, the refractive power has reduced. For a long time spectacles or contact lenses where the only way to increase the refractive power. This correction was of help for the individual, but spectacles or contact lenses also involved disadvantages. Spectacles give an enlargement of 20- 30 per cent. Contact lens involves management problems for the patient, in particular for old people. In both cases the individual may have problems because differences between the eyes. As an result many will only use one eye at a time.

In the late 70s a new technology in cataract surgery was introduced, an intraocular lens (IOL) implant following cataract extraction. After the introduction IOL has been further developed, especially with respect to complications. IOL has showed a rapid growth, in Sweden, from 7000 in 1980 to 44000 in 1996. Today almost all cataract surgery are carried out using IOL. The growth of IOL can mainly be explained by very good results for the patient and that IOL expanded the demand for treatment. In many cases the IOL increase health status, here visual acuity, often back to 'normal' acuity, an very good results on daily living activities have been observed. Today the technique also characterizes of a small risk for complications, and no side effects for the patient. The new IOL technology, and development of surgery, has also have effected hospital costs for a treatment. During the last 10 years the ambulatory surgery of IOL has increased and is the dominating procedure today. The change from inpatient care to ambulatory care has lowered hospital costs for treatment.

Cataract surgery will change the set of attainable input vectors, i.e., the set X_i for individual i. Health status in terms of visual acuity is expected to change. Other inputs as glasses, contact lens or services at home may also change. In the latter case we can observe a reduction of the need for help with house keeping, in particular for old people. Surgery may also change the set of feasible daily life activity vectors, i.e., the set of b_i - vectors for individual i.

Two recent studies, Lundström, Fregell and Sjöblom (1994) and Lundström et al (1997) investigate the impact of IOL on individuals ability to perform daily life activities for a sample of Swedish patients in 1995. Data from these two studies have been used by Lundstöm and Roos (1995) in an index approach measuring changes in daily life activities for patients undergoing IOL surgery using the Malmquist index in equation (2.4) above.

A short presentation data and result in the study by Lundström and Roos (1995) on effects on daily life activities is presented below. The sample consists of observations from 127 patients with cataract. The patients were interviewed before surgery and six months following surgery. The patients were asked about perceived problems within 37 specific daily life activities and eventual problems were also weighted by the patient. The six most decisive daily life activities were picked out to be used in the index. These activities were

- recognizing faces
- reading papers
- walking on uneven ground
- reading text on TV
- shopping
- doing needlework

These six activities are reported in the literature as frequently performed by older persons. The ability to perform these activities is dependent on either good visual acuity or good contrast sensitivity for lower or intermediate spatial frequencies. A routine ophthalmologic examination was also performed before surgery and after surgery including a six months control.

For each activity, the patient was asked about problems related to the activity. The questionnaire included four alternatives: *no problem*, *a small problem*, *a large problem*, and *a very large problem*. There is an ordinal scale for each activity. In the calculation of the index we need a cardinal scale. *No problem* was given a rank of 4, *small problem* rank 3, *large problem* rank 2 and *very large problem* rank 1. In this study, a higher rank indicates better opportunity to conduct daily life activities.

The two inputs in the index approach were two variables of health status; *binocular visual acuity* measured in dB and *binocular reading ability* measured in the Jaeger-scale. In the calculations the Jaeger-scale has been converted, so that the highest reading ability is ranked as 12 and the lowest ranked as 1. Higher levels of the two inputs correspond to an opportunity to conduct daily life activities.

Values to the distance function in (2.4) were calculated using the linear programming problems in (2.2 and 2.3). Although the index approach yields patient- specific results, we present more aggregated results. The results showed that the everyday activities increased after a cataract extraction, i.e., we have an observation outside the feasible set of activity levels as indicated by point T in Figure 2.1. The results indicate, on average, an increase by 60 percent, i.e., the ratio of two values to the distance function equal 1.60. For 108 patients (85%), the index indicated improvements, and for 14 patients (11%) deterioration. For 5 (4%) patients, the index showed no change.

As an illustration of the suggested index approach we have used figures from an earlier study on cataract extraction. In doing so the number of inputs, e.g., resources, have been confined to a vector consisting of visual acuity and reading ability. The potential of this method, however, makes it possible to build up a series of vectors giving information about all the important resources that the patient has before surgery that may influence the benefit from surgery.

We also would like to compare the outcome from the old way of treatment, i.e., extraction of the lens and optical correction with spectacles, with the new IOL technique. We have not found any study measuring the impact on basic life activities from the old way of treatment. The only study we have found in this area is study by Bernth- Petersen and Sorensen (1983). The study by Bernth- Petersen and Sorensen on highly selected sample of Danish patients reports improvements in vision dependent practical functionings with IOL compared with extraction and spectacles. As an hypothetical example we assume that extraction and spectacles have, on average, some impact on visual acuity and daily life activities, but less than the IOL technique. We assume that the old technique increase the daily life activities by 20 per cent, i.e., the index in equation 2.4, on average, equal 1.20. In this illustration output of a treatment have increased from 1.2 to 1.6 in terms of daily life activity units. With the output based on activity units we have had an increase in Sweden from 7000*1.2= 8400 in 1980 to 44000*1.6=70400 in 1996. That is an increase with 738 per cent. This increase can be compared with 529 per cent if we use number of treatments as a proxi for hospital output.

This illustation shows that we may under estimate hospital output if we define output as number of treatments, discharges etc., which in turn will create problems for management and, in particular, for the measurement of productivity changes.

3. Malmquist productivity and quality index

Traditional index approaches for the measurement of productivity changes assume that the observed prices of inputs and outputs can be used in the calculation of productivity change. These approaches also assume cost minimizing and/or revenue maximizing behavior on the part of the producer and equate productivity change with technological change. If we want to allow for technically inefficient observations, include cases where we do not have information on cost shares, revenue shares or when available price information is inapplicable or missing, the traditional index approaches are not very helpful.

Methods for calculations of productivity and quality indexes that allow for inefficiency, do not assume cost minimizing or revenue maximizing behavior, and only require quantity observations of inputs and outputs have recently been developed, i.e., so called Malmquist index approaches. The Malmquist index approaches have also been extended to allow for quality aspects. We think that the Malmquist index approaches will prove very useful for the measurement of productivity in the health care sector. For example, many hospital production characterizes of great complexity with many inputs and many outputs and price information is very often not applicable or missing. Examples of applications of Malmquist productivity index to hospital production are Färe, Grosskopf, Lindgren and Roos (1989, 1994), Färe, Grosskopf and Roos (1994), Magnussen (1994), Burgess and Wilson (1995), and Dervaux, Leleu and Jacobzone (1995). In all these applications hospital output is measured in terms of discharges, treatment, beddays etc., and changes in output in terms changes in health status and quality of life will not be captured.

There are a number of possible Malmquist index approaches, which provide us with a range of choices which vary in terms of the type of data required, and also provide a range of goals. For example, looking at Swedish pharmacies, where the government agreement requires that the pharmacies provide drugs at lowest possible costs and with high quality in the services to the customers, it seems reasonable to judge relative performance on that basis. A similar example can be constructed for many hospital services, but we can also think of situations where the overall goal of the operation is in terms of maximum level and quality of hospital services given a certain amount of resources or cost. That is, given the goal for the pharmacy or hospital, which may include both quantity aspects and quality aspects, the approach for measuring productivity should create incentives in line with the goal. As these examples suggest, the techniques are very flexible- they can be employed to assess performance even in cases where the usual signals like profit or revenues are nonexistent or inappropriate.The Malmquist index approach is, of course, also relevant in cases where we have information on prices. One may also think of situation where we have market observations on prices for some outputs but not for others, e.g., in the case when the producer have a mix of monopoly and non monopoly products.

3.1 Malmquist productivity and quality index approach

In the following a producer is a health care unit as,e.g., a hospital or department within a hospital. Let x be a vector of inputs and y a vector of outputs. Define the set $L(y)$ as the set of all input vectors that can produce y and the set $P(x)$ as the set of all output vectors that can be produced using x, given the production technology S. Formally,

(3.1)

S is the set of feasible input and output combinations (x,y)

$$L(y) = \{x: (x,y) \in S\}$$

$$P(x) = \{y: (x,y) \in S\}$$

To be able to construct the index, the technology underlying the production has to be modeled. For this purpose we present the output distance function denoted, $D_0(x,y)$ introduced by Shephard (1953,1970), see also Färe (1988) and Färe and Primont (1995). The input distance function is defined as

(3.2)

$$D_0(x,y) = inf\{\theta: y/\theta \in P(x)\}$$

The output distance function model the technology in terms of output isoquants and it provide a complete characterization of the underlying technology, see, e.g., Färe (1988). The two distance functions are used in order to identify the best practice frontier technology at each time period, using actual observations on inputs and outputs. The output distance function takes a value less than one at a point below the isoquant. The ouput and input distance function take a value equal to one for all points at the isoquant.

In each time period t, the frontier technology, S^t, models the transformation of inputs, x, into outputs, y. In measuring productivity change we focus on *changes in the technology and efficiency* in contrast to Malmquist who focuses on quantity index numbers. In the indexes below technology means best practice frontier technology. Below, we also show how inefficiency can be included into the productivity index and how the index can be extended to take into account some types of quality aspects.

Caves, Christensen and Diewert (1982) define a Malmquist output based productivity index in terms of output distance functions as;
(3.3)

$$M_o^{t+1}\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \sqrt{\frac{D_o^t\left(y^{t+1}, x^{t+1}\right) D_o^{t+1}\left(y^{t+1}, x^{t+1}\right)}{D_o^t\left(y^t, x^t\right) D_o^{t+1}\left(y^t, x^t\right)}}$$

The Malmquist output based productivity index equal a value larger than one in the case of productivity growth. Productivity regress is indicated by an index value less than one. If no change in productivity occurs the index equals one. If there are no change in observed inputs and outputs, i.e., $x^t = x^{t+1}$ and $y^t = y^{t+1}$, the two Malmquist productivity indicies will always both be equal to 1.

Allowing for inefficiency in the Malmquist productivity indicies was first noted by Färe, Grosskopf, Lindgren and Roos (1989,1994). In this case the time specific output distance functions in (3.2) take a value equal or less than 1, i.e., $D_0^t\left(x^t, y^t\right) \leq 1$ and $D_0^{t+1}\left(x^{t+1}, y^{t+1}\right) \leq 1$. For the mixed periods the distance function takes a value less, equal or more than 1.

The Malmquist productivity index in (3.3) can be rewritten and productivity change can be decomposed into a term measuring change in technical efficiency and a term measuring changes in the technology. In the latter case, technological change is calculated as changes in the frontier input isoquant or the frontier output isoquant. Following Färe et al the Malmquist output based productivity index can be decomposed into: (1) changes in technical efficiency and (2) changes in frontier technology, i.e., the two indexes are multiplically separable in two components as

(3.4)

$$M_0^{t+1}\left(y^{t+1}, x^{t+1}, y^t, x^t\right) = EC \times TC$$

The Malmquist productivity index allows for efficiency changes (EC) and technology changes (TC) to go in different directions. An increase in efficiency may occur together with regress in technology or vice versa. Of course, both EC and TC may change in the same direction. The decomposition of the index may have policy implications for hospital managers. Catching- up with best practice hospital, i.e., EC may have other implications for the hospital than change in TC.

In general, it is desirable that, productivity measurement also should reflect these quality aspects of the services provided. However, very often, the measurement method used accomodates quality aspects badly, or not at all, Dertouzos, Lester and Solow (1989).

To be a useful concept when studying the performance of a hospital we have to explain what quality is supposed to capture. We think of quality as aspects on the hospital technology which are controllable by hospital management. The quality aspects have a clear link to hospital inputs, and managers may be more or less succeful in allocating inputs among hospital activities. We may distinguish between two main groups of quality measures: (1) general characteristics of the technology, such as availability of services, queuing time, nursing, and (2) characteristics of the medical technology such as side effects and complications in surgery. In the latter case reduced risk of complications or reduced negative side effects may be of particular interest.

The above Malmquist index approach for measuring productivity can be extended to also capture quality aspects. The work by Färe et al has recently been extended to include quality attributes, or nonmarketed characteristics, of the technology into indexes of performance and productivity, Färe, Grosskopf and Roos (1995). This extension have some nice advatages compaired to many other approaches, that has been suggested in the literature. For example, quality aspects are included in the index.

In this case we denote inputs by $x^t \in R_+^N$, outputs by $y^t \in R_+^M$ and attributes by $a^t \in R_+^J$. The technology set at t is defined as $S^t = \left\{\left(x^t, y^t, a^t\right): x^t \mathit{can\ produce}\ y^t\ \mathit{and}\ a^t\right\}$.In words, the technology consists of all outputs and attributes that are feasible for some input vector. The attributes are here treated as outputs, and if one so wants, one may think of the vector $\left(y^t, a^t\right)$ as the output vector.

$$M_o^{t+1}\left(x^{t+1}, y^{t+1}, a^{t+1}, x^t, y^t, a^t\right) = \sqrt{\frac{D_o^t\left(y^{t+1}, x^{t+1}, a^{t+1}\right) D_o^{t+1}\left(y^{t+1}, x^{t+1}, a^{t+1}\right)}{D_o^t\left(y^t, x^t, a^t\right) D_o^{t+1}\left(y^t, x^t, a^t\right)}}$$

The extended Malmquist productivity and quality change index can be decomposed into change in technical efficiency (EC), change in technology (TC) and quality changes (QC).

(3.5)

$$M_0^{t+1}\left(y^{t+1}, a^{t+1}, x^{t+1}, y^t, a^t, x^t\right) = EC \times TC \times QC$$

The decomposition provide us with information on sources of productivity change, including changes in quality. This will have policy implications. For example, if productivity changes is mainly explained by changes in quality, regress or progress. It could also prove useful when studing the effects from, for example, cutting hospital expenditures.

The above presented Malmquist productivity indexes can be calculated as solutions to linear programming problems.

3.2 An illustration to cataract surgery

The total number of cataract treatment in Sweden has increased from 7000 in 1980 to 44000 in 1996, see Figure 3.1. The frequency of the IOL technique has increased over time, and today almost all cataract surgery uses IOL, and very few is carried out with the old technique (extraction plus spectacles or contact lenses).

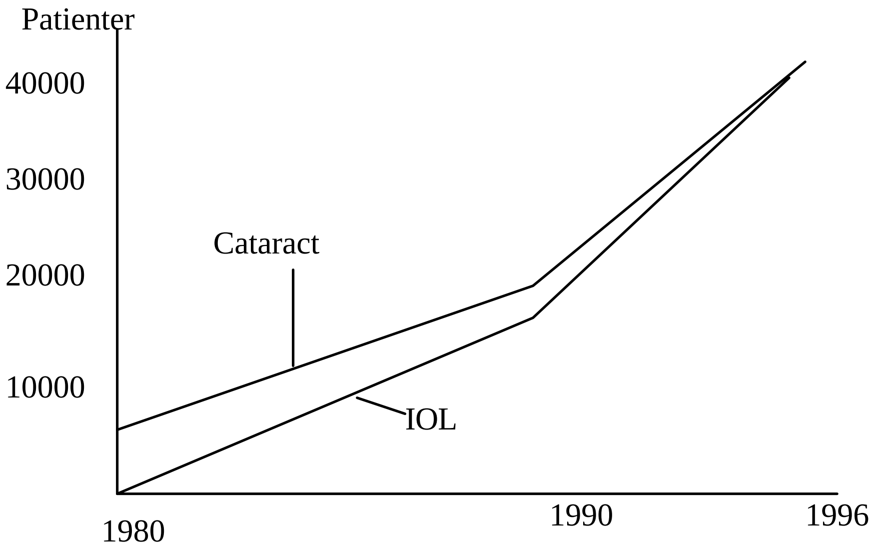

Figure 3.1. Cataract surgery in Sweden 1980-1996.

The introduction of IOL have had an positive effect on benefits for the individual. As the illustration in section 2 indicates the output has greatly increased in terms of individual's ability to perform daily life activities. Looking at the surgery process the risk for complications, mainly infections has decreased over time due to improvements in the IOL technique. The reduction of risk for complications, from 2-3 % in 1980 to 1-2 % in 1996 indicates an improvement in quality surgery. In the late 80s a new type of surgery within the IOL concept was introduced. As a result of this development patients can be treated in ambulatory care instead of inpatient care. Today almost all IOL treatments are carried out as ambulatory care.
The cost for treatment has decreased due to the introduction of IOL. In fixed years prices, the cost has decreased from $3 500 in 1980 to $ 1000 in 1996. All together the development in cataract surgery indicates a very large positive improvement in productivity.

In an empirical application measuring productivity changes we would like to have annual observations on inputs, outputs and quality from a sample of eye surgery departments. Such data has not been available in this study. However, in order to illustrate the Malmquist productivity index approach we use the only observations that we have, i.e., total number of surgery and indicators of average risk for complications and costs, together with the assumption of changes in health status and daily life activities as presented in section 2. The year is 1980 and 1996. Instead of real input, e.g., hours worked by labor, we use costs. A cost based Malmquist approach has earlier been used in an application to hospitals by Färe, Grosskopf and Roos (1994). The data is presented in Table 3.1.

Table 3.1 Illustration to cataract surgery in Sweden. 1980 to 1996

Output		
1.Number of patients	7000	44000
2.Average change in daily life activities, equation 2.4.	1.2	1.6
Quality		
1. Risk for complication	2%	1%
Input		
1.Total costs for treatment in fixed years prices (milj. $)	24,5	44,0

In this illustration productivity, calculated with a Malmquist index approach, shows an increase between 1980 and 1996 with 425% or with 25% per year. This result can be compared with 250 % increase, or 15% per year, if we base our calculation on only number of patients and costs. In the latter case we underestimate productivity change.

In the very simple illustration above, it is not possible to decompose productivity change into changes in efficiency, i.e., catching -up, changes in technology, and changes in quality. In an empirical application with data from many eye departments this is possible, and the decomposition will provide us with valuable information, e.g., with respect to management and policy.

4. Discussion

In this paper we discuss methodological issues in the measurement of productivity change in hospital services. We think that Malmquist index approaches can prove very useful in the measurement of productivity, due to the complexity of these services. The illustration to cataract surgery shows the applicability of these indexes, but also to the requirements of data. Data on inputs, quality, health status, and number of patients, visits etc. are very often collected at the hospital, but very often not easily available. Information on effects for the individuals in terms of daily life activities has to be collected by, e.g., questionnaires. This is very often done in clinical trials of new drugs, but also in some cases for the evaluation of new types of surgery or other treatments. In the future, it is more and more important to have information of benefits for the patients. If not, the risk for misleading information about, e.g., productivity change, may be very high.

References

Bernth- Petersen, P. (1981) Visual functioning in cataract patients. Methods of measuring results. *Acta Ophthalmol* (Copenhagen), 59, 198-205.

.

Björk, S. & P. Roos. (1994). "Analyzing changes in health related Quality of Life", In *Quality of Life: Concepts and Measurements,* L. Nordenfelt (ed.). Dordrecht: Kluwer Academic Publishers.

Brooks, R. (1995). *Health Status Measurement: A Perspective on Change.* MacMillan Press.

Brock, D. (1993). "Quality of Life Measures in Health Care and Medical Ethics". In *The Quality of Life,* Nussbaum, M. C., and Sen, A. (eds.) Clarendon Press, Oxford.

Caves, D.W., L.R. Christensen and W.E. Diewert. (1982). "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity." *Econometrica* 50, pp.1393-1414.

Detouzos, M. L., R. K. Lester and R. M. Solow (1989). Made in America- Regaining the productive Edge. The MIT Press, Cambridge, Massachusetts.

Grossman, M. (1972). *The Demand for Health: A Theoretical and Empirical Investigation.* New York: Columbia University Press for the National Bureau of Economic Research.

Häkkinen, U. (1991). "The Production of Health and the Demand for Health Care in Finland." *Social Sience of Medicine* 3, pp. 225-237.

Färe, R. (1988). *Fundamentals of Production Theory*. Berlin: Springer-Verlag.

Färe, R. and D. Primont (1995). *Multi- Output Production and Duality: Theory and Applications.* Kluwer Academic Publishers.

Färe,R., S. Grosskopf and P. Roos. (1995). "Productivity and quality changes in Swedish Pharmacies". *International Journal of Production Economics.*

Färe,R., S. Grosskopf and P. Roos. (1994). Produktivitetsutveckling inom sjukhussektorn 1970-1992. Finansdepartementet (Ministry of Finance), Ds Fi 1994:71.

Färe,R., S. Grosskopf, B. Lindgren and P. Roos. (1989). "Productivity Developments in Swedish Hospitals: A Malmquist Output Index Approach." Discussion Paper 89-3, Department of Economics, Southern Illinois University, Carbondale.

Färe,R., S. Grosskopf, B. Lindgren and P. Roos. (1994). "Productivity Developments in Swedish Hospitals: A Malmquist Output Index Approach." In Charnes, A., W.W. Cooper, A.Y. Lewin, and L.M. Seiford, (eds.) *Data Envelopment Analysis: Theory, Methods and Applications.*

Lundström, M., Fregell, G., and Sjöblom, A. (1994). "Vision related daily life problems in patients waiting for cataract extraction". *Br J of Ophthalmol,* 78, 608-611.

Lundström, M., Roos, P., Jensen, S. and Fregell, G. (1997). "The Cataract Questionnaire (CATQUEST): A questionnaire to be used in cataract surgery care". *Journal of Cataract and Refractive Surgery*. Forthcoming.

Lundström, M. and Roos P. (1995). "Outcome of cataract extraction: An index approach for measuring patient benefits. IHE- working paper 1995:2.

Malmquist, S. (1953). "Index Numbers and Indifference Surfaces." *Trabajos de Estatistica,* pp. 209-242.

Muurinen, J.-M. (1982). "Demand for health: a generalised Grossman model." *Journal of Health Economics* 1, pp. 5-28.

Patrick, D. L., and Erickson, P. (1992). *Health Status and Policy: Quality of Life in Health Care Evaluation and Resource Allocation.* Oxford University Press.

Roos, P., & Björk, S. Health Status and Quality of life indices — a non-parametric approach. IHE-working paper 1992:7. The Swedish Institute for Health Economics, 1992.

Sen, A. (1985). *Commodities and Capabilities*. Amsterdam: North-Holland.

Sen, A. (1993). Capability and Well- Being. In *The Quality of Life*, Nussbaum, M., C. and Sen, A. (eds). Clarendon Press, Oxford.

Shephard, R. (1953). *Cost and Production Functions.* Princeton: Princeton University Press.

Shephard, R. (1970). *Theory of Cost and Production Functions*. Princeton: Princeton University Press.

Wagstaff, A. (1986). " The demand for Health. Some new empirical evidence." *Journal of Health Economics* 5, pp. 195-233.

Zeifel, P. and Breyer, F. (1995). *Health Economics*.