Productivity? of U.S. Airlines After Deregulation[1]

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Abstract

In measuring productivity in the presence of undesirable outputs, traditional growth accounting and index number approaches face the problem that prices of the undesirable outputs typically do not exist since such outputs are generally not marketed. In this paper we employ an alternative measure of total factor productivity based on a generalization of the Shephard distance functions, namely what we call directional output distance functions. Not only are these distance functions generally computable in the presence of undesirable outputs, but they also allow us to 'credit' firms for reductions in undesirable outputs, while crediting them for increases in good outputs. The Luenberger productivity indicator is constructed from directional distance functions, but in contrast to the Malmquist index, it has an additive structure. We analyze a sample of airline firms most recently examined by Alam and Sickles (2000) and extend it to include an index of circuity as one of our measures of an undesirable output of airline travel. An addiitonal measure of an undesireable output of airline travel is timeliness and is measured by FAA data on percent of flights that arrived on time. The two 'good' outputs are scheduled and nonscheduled revenue passenger miles. We find that accounting for characteristics such as circuity and percentage of flights arriving on time does affect productivity. Our findings confirm anecdotal accounts of a decline in airline service productivity since deregulation, yielding in general lower rates of productivity growth in our sample when bads such as indirect routing and delays are explicitly introduced into the technology.

1 Introduction

The purpose of this paper is to provide estimates of total factor productivity (TFP) growth for U. S. airlines, while taking account of some of the negative effects on consumers of the increased inconvenience ('circularity') that arises out of increasing reliance on the hub and spoke system. The measure of total factor productivity we use allows us to directly include our measure of this inconvenience, and treat it as an undesireable output. In addition, the productivity measure we use does not require data on prices, which is particularly useful in our application since we do not have a price for our undesirable output.

We provide an overview of some approaches to modeling and measuring productivity in the presence of joint production of desirable and undesirable outputs. These have in common an axiomatic production theoretic framework, in which joint production is explicitly modeled using the notion of null-jointness proposed by Shephard and Färe, and weak disposability of outputs is imposed to model the fact that reduction of bad outputs may be costly. In measuring productivity in the presence of undesirable outputs, traditional growth accounting and index number approaches face the problem that prices of the undesirable outputs typically do not exist since such outputs are generally not marketed. An alternative which does not require price information is the Malmquist productivity index which is based on ratios of Shephard type distance functions. These do not require information on prices, which suggests that they would be an appropriate methodological tool.

Although an improvement over ignoring undesirable outputs, the Malmquist index computed with bads may not have well-defined solutions, and it effectively registers increases in the bads (like the goods), ceteris paribus, as improvements in productivity. In order to address these problems we employ an alternative measure of TFP based on a generalization of the Shephard distance functions, namely what we call directional output distance functions. Not only are these distance functions generally computable in the presence of undesirable outputs, but they also allow us to 'credit' firms for *reductions* in undesirable outputs, while crediting them for *increases* in good outputs. The Luenberger productivity indicator is constructed from directional distance functions, but in contrast to the Malmquist index, it has an additive structure. Both are easily computable using linear programming techniques very similar to traditional data envelopment analysis.

We analyze a sample of airline firms most recently examined by Alam and Sickles (2000) and extend it to include an index of circuity as one of our measures of an undesirable output of airline travel. The data set covers 13 carriers during the period from 1979I to 1994IV quarterly. The additional measure of an undesireable output of airline travel is timeliness and is measured by FAA data on percent of flights that arrived on time. It is available from 1987I to 1994IV for a subset of 10 of the carriers in the original sample. The specification of inputs and characteristics is the same in both cases; inputs: labor, energy, materials, long and short haul flying capital; characteristics of capital equipment such as the average size of the planes in the fleet, average age of the fleet, and a fuel efficiency index; characteristics of the system network as measured by average stage length of the carrier's flights and system load factor. The two 'good' outputs are scheduled and nonscheduled revenue passenger miles.

As part of our exercise we compare productivity with and without our measure of inconvenience. Any loss in productivity is an indirect measure of the cost of reducing circularity in the system. It also provides an estimate of the potential upward bias of ignoring the impact of circularity on consumers. Our productivity measure–which we refer to as Luenberger total factor productivity–is estimated using frontier techniques. Thus, like the somewhat more familiar Malmquist productivity index, it may be decomposed into efficiency change and technical change. Thus we may also see whether accounting for circularity results in reduced efficiency, or a shift in the frontier of technology. To anticipate our major results, we find that accounting for characteristics such as circuity and percentage of flights arriving on time does affect productivity. Our results confirm anecdotal accounts of a decline in service since deregulation, yielding in general lower rates of productivity growth in our sample when bads such as indirect routing and delays are explicitly introduced into the technology.

The paper begins with a discussion of how we model the joint production of desirable and undesirable outputs both conceptually and empirically. Next we turn to a discussion of the Luenberger Productivity Indicator in Section 3. Section 4 discusses the data used in our empirical illustration. Results are provided in section 5 and section 6 concludes.

2 Modeling Technologies with Good and Bad Outputs

The production of desirable outputs is often accompanied by the simultaneous or joint production of undesirable outputs. In our case the desirable outputs are passenger and freight miles, and the undesirable output is 'circularity', which is a measure of the inconvenience to customers caused by flying with the hub and spoke system.

If we wish to measure productivity when both desirable and undesirable outputs are produced, we should obviously explicitly account for their joint production. If we denote desirable outputs by $y \in \Re^M_+$, undesirable outputs by $b \in \Re^I_+$, and inputs by $x \in \Re^N_+$, then the technology may be written as

$$T = \{(x, y, b) : x \text{ can produce } (y, b)\}. \quad (1)$$

The technology consists of all feasible input and output quantities, i.e., it consists of all desirable and undesirable outputs that can be produced by the given input vectors.

To model the joint production of the good and bad outputs, it is convenient to model the technology in terms of the output sets, i.e.,

$$P(x) = \{(y, b) : (x, y, b) \in T\}. \quad (2)$$

Clearly T can be recovered from $P(x)$ as

$$T = \{(x, y, b) : (y, b) \in P(x), x \in \Re^M_+\}. \quad (3)$$

Thus the technology is equivalently represented by either its output sets $P(x), x \in \Re^N_+$ or its technology set T.

One important feature from the viewpoint of the airlines, is that it is costly to reduce circularity. This idea is modeled by imposing what we call Weak Disposability of Outputs, i.e.,

$$(y, b) \in P(x) \text{ and } 0 \leqq \theta \leqq 1 \text{ imply } (\theta y, \theta b) \in P(x). \quad (4)$$

In words this states that reduction of undesirable outputs is feasible if good outputs are also reduced, given fixed input levels.[1] Hence it may be infeasible to reduce the undesirable outputs only, i.e, if (y, b) is feasible and $b' < b$ then it may be impossible to produce (y, b') using x, i.e, $(y, b) \in P(x)$ and $(y, b') \notin P(x)$. Clearly if undesirable outputs could be disposed of costlessly (freely), then this problem would not arise. One reason for distinguishing between desirable and undesirable outputs in terms of their disposability is that the former typically have positive prices, whereas the latter are typically non marketable and therefore do not have readily observable prices.

The notion that desirable and undesirable outputs are jointly produced is modeled by what Shephard and Färe (1974) call null-jointness. In words this means that if no bad outputs are produced, then there can be no production of good outputs. Alternatively, if one wishes to produce some good outputs then there will be byproducts of bad outputs. More formally, we have

$$(y, b) \in P(x) \text{ and } b = 0 \text{ then } y = 0, \tag{5}$$

i.e., if (y, b) is a feasible output vector consisting of desirable outputs y and undesirable outputs b, then if no undesirable outputs are produced $(b = 0)$ then by null-jointness, production of positive desirable outputs is not feasible, so $y = 0$.

In order to develop a framework for the empirical measurement of productivity with good and bad outputs we need to formulate an explicit reference technology. Here we assume that at each time period $t = 1, \ldots, \bar{t}$ there are $k = 1, \ldots, K$ observations of inputs and outputs,

$$(x^{t,k}, y^{t,k}, b^{t,k}),\ k = 1, \ldots, K,\ t = 1, \ldots, \bar{t}. \tag{6}$$

Following Färe, Grosskopf and Lovell (1994) we define the output sets from the data as an

[1] With respect to the good outputs, we assume that they are freely or strongly disposable, i.e., $(y, b) \in P(x)$ and $y' \leqq y$ imply $(y', b) \in P(x)$.

activity analysis or data envelopment analysis (DEA) model, namely

$$\begin{aligned} P^t(x^t) \;=\{(y^t,b^t):\ & \textstyle\sum_{k=1}^K z_k^t y_{km}^t \geqq y_m^t, \quad m=1,\ldots,M, \\ & \textstyle\sum_{k=1}^K z_k^t b_{ki}^t \;=\; b_i^t, \quad i=1,\ldots,I, \\ & \textstyle\sum_{k=1}^K z_k^t x_{kn}^t \leqq x_n^t, \quad n=1,\ldots,N \\ & z_k^t \geqq 0, \qquad k=1,\ldots,K\}, \end{aligned} \tag{7}$$

where z_k^t are the intensity variables, which serve to form the technology from convex combinations of the data.

In general one can show that model (7) satisfies (4) and (5) in addition to satisfying constant returns to scale, i.e.,

$$P(\lambda x) \;=\; \lambda P(x), \lambda > 0. \tag{8}$$

For the good and bad outputs to satisfy null-jointness at each period t, we need to assume that the bad outputs satisfy the following two conditions:

$$\begin{aligned} \sum_{k=1}^K b_{ki}^t > 0, & \quad i = 1 \ldots, I, \\ \sum_{i=1}^I b_{ki}^t > 0, & \quad k = 1 \ldots, K. \end{aligned}$$

The first inequality says that each bad is produced by at least one firm. The second states that each firm produces at least one bad. Now, referring back to the activity analysis formulation of technology in (7), suppose that the right hand side of the constraints on the bad outputs are such that $b_i^t = 0, i = 1, \ldots, I$. If we have null-jointness that means that we should also have $y_m^t = 0, m = 1, \ldots, M$. The inequalities above guarantee that this is so, since together they require that each intensity variable is multiplied by at least one non zero value of b_{ki}^t. Thus the only way to have $\sum_{k=1}^K z_k^t b_{km}^t = 0$ when these constraints hold is to have $z_k^t = 0$ for all k, which would imply that $y_m^t = 0, m = 1, \ldots, M$ as required for null-jointness of y and b.

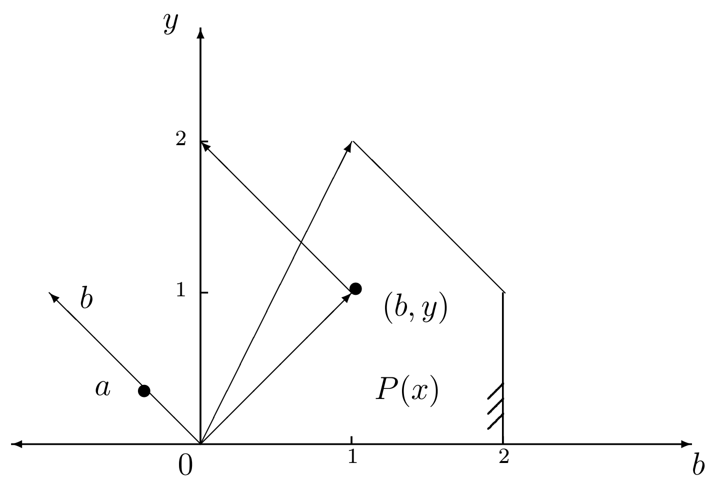

Figure 1: Directional output distance function with good and bad outputs

3 The Luenberger Productivity Indicator

The productivity indicator which we employ is an output-oriented version of the Luenberger productivity indicator introduced by Chambers (1996). It is based on the output-oriented directional distance function, which is a generalization of a Shephard output distance function. Instead of scaling on all outputs proportionally as in the Shephard output distance function, the directional output distance function allows us to scale the output in specific direction, in our case we are increasing desirable outputs and decreasing undesirable outputs.

In particular, consider a direction $(g_y, -g_b) \neq 0$ where $g_y \in \Re^M_+$ and $g_b \in \Re^I_+$, then the output-oriented directional distance function is defined as

$$\vec{D}_o(x, y, b; g_y, -g_b) = \sup\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\}. \tag{9}$$

This function is defined by adding the direction vector to the observed vector and scaling that point by simultaneously increasing good outputs and decreasing bad outputs. The following figure illustrates.

In this figure the output set is denoted by $P(x)$ and the output vector (y, b) is an element of that set. The direction vector is $(g_y, -g_b)$ and the distance function expands the output vector as much as is feasible along the direction vector. It ends up at $(y + \vec{D}_o g_y, b - \vec{D}_o g_b)$, where $\vec{D}_o = \vec{D}_o(x, y, b; g_y, -g_b)$.

In order to see the relation between the directional and the Shephard output distance function, suppose we change the direction slightly (eliminate the negative sign on the bad outputs) and choose $g_y = y$ and $g_b = b$, then

$$\begin{aligned}
\vec{D}_o(x, y, b; y, b) &= \sup\{\beta : (y + \beta y, b + \beta b) \in P(x)\} \qquad (10)\\
&= \sup\{\beta : (y(1 + \beta), b(1 + \beta) \in P(x)\}\\
&= \sup\{1 - 1 + \beta : (y(1 + \beta), b(1 + \beta) \in P(x)\}\\
&= -1 + \sup\{(1 + \beta) : (y(1 + \beta), b(1 + \beta) \in P(x)\}\\
&= 1/D_o(x, y, b) - 1,
\end{aligned}$$

where $D_o(x, y, b)$ is the traditional Shephard output distance function. Thus if we choose the directions $g_y = y$ and $g_b = b$, we find that the directional distance function is essentially Shephard's output distance function. To sum up,

$$\vec{D}_o(x, y, b; y, b) = (1/D_o(x, y, b)) - 1. \qquad (11)$$

or

$$D_o(x, y, b) = \frac{1}{1 + \vec{D}_o(x, y, b; y, b)}. \qquad (12)$$

We now turn to the Luenberger productivity indicator. We define it as

$$\begin{aligned}
L_t^{t+1} = \; & 1/2(\vec{D}_o^{\,t+1}(x^t, y^t, b^t; y^t, -b^t) - \vec{D}_o^{\,t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) \qquad (13)\\
& + \vec{D}_o^{\,t}(x^t, y^t, b^t; y^t, -b^t) - \vec{D}_o^{\,t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})).
\end{aligned}$$

In our empirical application, we take the direction $(g_y, -g_b)$ to be the observed values of the good y and bad b outputs. Following the idea of Chambers, Färe and Grosskopf (1996) the Luenberger indicator can be additively decomposed into an efficiency change and a technical change component,

$$LEFFCH_t^{t+1} = \vec{D}_o^{\,t}(x^t, y^t, b^t; y^t, -b^t) - \vec{D}_o^{\,t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) \tag{14}$$

and

$$\begin{aligned} LTECH_t^{t+1} = \quad & 1/2(\vec{D}_o^{\,t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) - \\ & \vec{D}_o^{\,t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) + \vec{D}_o^{\,t+1}(x^t, y^t, b^t; y^t, -b^t) \\ & -\vec{D}_o^{\,t}(x^t, y^t, b^t; y^t, -b^t)), \end{aligned} \tag{15}$$

respectively. The sum of these two components equals the productivity indicator.

In passing we note that one may also define a Luenberger productivity indicator based on a directional technology distance function, which in addition to scaling on good outputs, also scales on the input vector. It has the advantage of being dual to the profit function, which implies that it is a natural component of profit efficiency. This type of Luenberger productivity indicator was employed by Chambers, Färe and Grosskopf (1996).

The directional distance functions, like the Shephard distance functions, can be calculated as solutions to linear programming problems. As an example, let us consider the $(k', t+1)$ observation of data relative to the period t reference technology, i.e.,

$$\begin{aligned} \vec{D}_o^{\,t}(x^{t+1,k'}, y^{t+1,k'}, b^{t+1,k'}; y^{t+1,k'}, -b^{t+1,k'}) &= \max\ \beta \\ \text{subject to} & \\ \sum_{k=1}^{K} z_k^t y_{km}^t &\geqq (1+\beta) y_{k'm}^{t+1},\ m = 1, \ldots, M, \\ \sum_{k=1}^{K} z_k^t b_{ki}^t &= (1-\beta) b_{k'i}^{t+1},\ i = 1, \ldots, I, \\ \sum_{k=1}^{K} z_k^t x_{kn}^t &\leqq x_{k'n}^{t+1},\ n = 1, \ldots, N \\ z_k^t &\geqq 0,\ k = 1, \ldots, K. \end{aligned} \tag{16}$$

Next we turn to our empirical illustration and then to our estimation results.

4 Application to the U.S. Airline Industry

In this section we provide a discussion of the variables used in our measurement of productivity in the presence of undesirable outputs.

4.1 Input and Output Data

The labor input was composed of 93 separate labor accounts aggregated into five major employment classes (flight deck crews, flight attendants, mechanics, passenger/cargo/aircraft handlers, and other personal). Using the expense and head count information from above, the expense per person quarter and the number of person quarters were calculated. The multilateral Törnqvist-Theil price and quantity indices for the labor input were then derived.

The objective of the energy input category is to capture aircraft fuel only. Fuel that is used for ground operations and electricity are both captured in the materials index. The energy input was developed by combining information on aircraft fuel gallons used with fuel expense data per period. This input has undergone virtually no change because these accounts remained substantially unchanged over the 23-year span of our data set. The multilateral Törnqvist-Theil index number procedure is used to provide normalization of the data.

The materials input is comprised of 69 separate expenditure accounts aggregated into 12 broad classes of materials or other inputs that did not fit into the labor, energy, or flight capital categories. Carrier-specific price or quantity deflators for these expenditure groups were unavailable. Instead, industry-wide price deflators were obtained from a variety of sources. These price deflators were normalized to 1.0 in the third quarter of 1972.

The number of aircraft that a carrier operated from each different model of aircraft in the airline's fleet is available from DOT Form 41, Schedule T2. Data on the technological characteristics for the approximately 60 types of aircraft in significant use over the period 1970 through 1992 were collected from *Jane's All the World's Aircraft* (1945 through 1982 editions). The average number of aircraft in service was constructed by dividing the total number of aircraft days for all aircraft types by the number of days in the quarter. This provides a gross measure of the size of the fleet (number of aircraft).

In order to adjust this measure of flight capital, we also construct the average equipment size. This was measured with the highest density single-class seating configuration listed in *Jane's* for each aircraft type. The fleet wide average was weighted by the number of aircraft of each type assigned into service. In some cases, particularly with wide-bodied jets, the actual number of seats was substantially less than described by this configuration because of the use of first-class and business-class seating. Our purpose was to describe the physical size of the aircraft rather than how carriers chose to use or configure them.

We use the average number of months since the FAA's type-certification of aircraft designs as our measure of fleet vintage. Our assumption is that the technological innovation in an aircraft does not change after the design is type-certified. Consequently, our measure of technological age does not fully capture the deterioration in capital and increased maintenance costs caused by use. Our measure does capture retrofitting older designs with major innovations, if these innovations were significant enough to require recertification of the type. Finally, it is clear that the major innovation that took place during the 1960s and 1970s was the conversion to jet aircraft. While many carriers had largely adopted this innovation prior to the study period, it was by no means universal. Many of the local service airlines used turboprop aircraft as a significant portion of their fleets. We implement this aspect by measuring the proportion of aircraft in the fleet that are jet powered. The proportion of wide-bodied aircraft was also calculated.

Revenue output is disaggregated into scheduled and nonscheduled output. Nonscheduled output includes cargo and charter operations. The price per unit (passenger-mile or ton-mile) of the relevant service as constructed by dividing the revenue generated in the category by the physical amount of output in that category. These prices were normalized to 1.0 in the baseline period. In cases where a carrier offered only one type of service (the convention was to call this "first class"), the service was redefined to be coach class. The Törnqvist-Theil index number procedure was used in constructing the two categories of service.

4.2 Network Configuration

Much has been made out of changes in airline networks by increased use of hub-and-spoke type networks. Airlines find these network configurations useful because they allow for higher passenger densities on individual routes. For example, in a simple network involving 5 cities (one centrally located), these cities can be connected with at most one change of plane service with as few as 4 flights. Connecting these cities together with a network where there is nonstop service would require 20 flights. Indirect routing of passengers clearly benefits the airlines because they can provide travel to passengers with fewer flights, potentially taking advantage of economies of equipment size (larger aircraft tend to have lower costs per passenger mile) and higher load factors (filling otherwise empty seats on an aircraft cost the airline very little).

In general, indirect routing of passengers is something that passengers would like to avoid. Their time is valuable. Indirectly routing a passenger, especially when it involves changes of planes is definitely less desirable than a direct flight. There are some exceptions to this. Indirectly routed passengers often will accrue more frequent flyer miles than a directly routed passenger. Other characteristics involving network configuration for passengers include origin-destination combinations for which no airline offers service. These situations require that a passenger take part of their trip on one airline and the remainder on at least one other airline. This interlining is generally considered a lower quality of service for the passenger than if their entire trip was on a single airline. Changing airlines is perceived to increase the likelihood that baggage will be mishandled or misdirected, it also typically increases the distance between gates at the connecting airport. The passenger also perceives reduced coordination between the carrier on the first segment and the second. The Department of Transportation's Origin/Destination database DB1A provides a 10% sample of all domestic tickets and allows us to identify many of the characteristics of the trip. Most fundamentally, we can identify the origin of a trip, and the ultimate destination as indicated by a trip break. Approximately 95% of trips are either one way or round trip (depending on the year) with a small number of multibreak tickets involving as many as 23 different flights. More complex routings tend to be slightly more prevalent in later years than in earlier ones.

The ticket itinerary allows us to measure the number of airlines taking part in the trip as well as a count of the number of times the airline changes (interlines). The changing patterns over our study period for these characteristics for one way and round trip tickets are summarized in Figures 1 and 2. For one way tickets, the number of airlines (NALINS) and the number of interlines (INTER) are very nearly the same. 28% of the tickets had more than one airline and the average number of interlines was 28% in 1979-1. By 1992-4 only 4% had passengers interlined. The pattern for round trip tickets is quite similar. In 1979-1 nearly half of the round trip itineraries involved more than one airline. Some of these involved more than one interline as an itinerary started with one carrier, switched to a second, then went back to the first carrier on the return. The information from the Origin and Destination data also allow us to measure the number of segments in a ticket. While these are not considered as a bad, from the passengers perspective, as an interline, a new segment does require that a change of plane occur. These are summarized for one way and round trip tickets in Figure 3.

The minimum number of segments for a one way ticket is one. Figure 3 shows that approximately half of the one way itineraries involved an additional segment in 1979-1. But this number fell by 1984 to between 25%. Again, this demonstrates an improvement in the quality of airline service as fewer changes of plane appear to be required. A very different pattern emerges for round trip tickets which have a minimum of two segments. In 1979-1 the average number of segments was 2.8, this increased somewhat to 3.05 by 1992-4 indicating a reduction in the quality of service. At 3.0 it suggests that approximately half of the itineraries involved a change of planes on the outbound and inbound portions of the trip. The rationale behind the difference in the one way and round trip ticket patterns is not clear. It may suggest a correlation between one way and full fare tickets which have a higher quality of demanded service for the large premium in price. On the other hand, while the presumption behind round trip tickets is that they describe the full trip, we know that not to be the case for one way tickets since the passenger will require, at the minimum, an additional ticket for the return flight. Consequently the presumption that a full fare ticket involves the ultimate destination seems less well founded.

An additional way to characterize the network quality associated with a particular ticket is to examine its circuity (Figure 4). An indirect routing forces the passenger to travel additional miles than they would prefer. We measure the circuity of an itinerary by adding up the miles associated with each ticket segment (measured by the great circle distances which corrects for the curvature of the earth) and dividing it by the number of miles associated with a direct routing of the passenger (again measured with great circle distances). Figure 4 indicates a small amount of circuity associated with trips, averaging 5% for both one way and round trip tickets. This is generally declining slightly for one way tickets and increasing slightly for round trip tickets and suggests that while changes of planes may be necessary, they occur at an airport which is in the same direction as a direct routing would take the traveler. Circuity does not allow us to capture indirect routing which does not involve a change of planes since we do not have any information on the routing of flights or flight numbers in the OD data.

4.3 Flight convenience and availability

Passengers typically have clear preferences regarding the time of travel. This may involve a clear preference as to the time of departure or the time of arrival at the destination. The willingness to accept other flight times vary a great deal with trip purpose. Two measures of service quality that deal with the availability of a seat at the time desired are flight frequency and load factor. Flight frequency at the airport level is the number of scheduled departures over the quarter and is based on the Department of Transportation's Airport Activity Statistics. As more and more departures are offered at an airport, the average amount of schedule delay (the delay which occurs between the desired time and actual time) decreases. The patterns for different airport categories are summarized in Figure 5. These categories include the average daily departures for large airports ranked in the top 20 airports, medium sized airports ranked from 100-120, small airports ranked from 300-320 and very small airports ranked 400-420 in terms of their total enplanements between 1979 and 1992. The figures indicate that there has been an increase of approximately 34% in the daily departures for the large airports, a 20% increase in the daily departures for medium sized and small airports, and an 80% reduction in the number of daily departures for very small airports.

Simply because there is a departure is no guarantee that a seat will be available. Airlines with a high load factor will have a propensity to fill a larger fraction of their flights. High load factors may be a good thing from the perspective of the airlines (filling otherwise empty seats has a very low cost associated with it) but not from the perspective of the passenger. Unfortunately, we do not have load factor at any level of detail other than the carrier level during the quarter. This is generally related to flight frequency with a lower number indicating more frequent flights and consequently a higher level of service. Other definitions of load factor are possible, such as dividing the total passenger revenue collected by the total that would be collected were the planes flown full (derived from the passenger capacity output times passenger capacity price). The data suggests that there has been a slight decline in the availability of flights over the study period. There are other potential measurement approaches for assessing changes in this aspect of service at more detailed levels. Finding out that a flight is not available can occur at the time reservations are made or during boarding. DOT maintains data on the number of passengers denied boarding either voluntarily or involuntarily. Involuntary denials are very rare since carriers offer passengers fairly good inducements to delay their travel plans (typically free tickets along with first class upgrades and hotel accommodations if necessary for accepting the next flight out).

Another important measure of the carrier's network is stage length which also provides another aspect of carrier output. Generally, the shorter the flight, the higher the proportion of ground services required per passenger-mile and the more circuitous the flight (a higher proportion of aircraft miles flown is needed to accommodate the needs of air traffic control). This generally results in a higher cost per mile for short flights than for longer flights. Average stage length is found by dividing total revenue aircraft miles flown by total revenue aircraft departures.

4.4 Airport Congestion and flight delay

Flight delays are an important aspect of service quality. Passengers have a great deal of anxiety over missed connections and delayed or canceled flights. The Department of Transportation currently maintains detailed flight delay information on an individual flight basis. However, as with any measure for service quality these delay data are not perfect measures for our purposes. First, it is available only starting in September of 1987, more than half way through our study period. Second, it is very expensive. This data would cost $10,800 for the six years in our study period and over $20,000 for data through 1998. Third, the delay data essentially has changed its meaning over time. Airlines have recognized that passengers use delay information in the selection of flights. They have countered this by increasing the scheduled duration of the flight to increase on-time performance. Fourth, a paramount objective in the nation's air traffic system is safety. Flight delays are not included in the aggregate delay statistics for weather or equipment safety reasons to eliminate any incentive to improve apparent service quality at the expense of safety. Reservations systems have countered this by incorporating both the scheduled duration of the flight and delay information into their prioritization of flights for display. The good features of this data are that it provides very detailed information on actual flight operations. It provides information on taxi time both on takeoff and departure, and time in flight along with scheduled departure and arrival times. This allows us to identify airport congestion as well as flight specific delay information. On the other hand, while not impossible, connecting this information to the origin and destination ticket information is far from a trivial exercise. It would require getting an airline specific aggregation of flight segments over the quarter of all of those flights which provided direct or multi-stop service on a particular coupon segment. In order to measure airport congestion and flight frequency we utilze FAA data on flight delays during a quarter for a carrier. These are displayed in Figure 6 and show a slight downward trend in the percent of flights that arrived on time for the airlines in our sample.

5 Estimation Results

The original data which includes the index of circularity (one of our measures of an undesirable output of airline travel) covers the period from 1979 to 1994, includes 13 carriers and is quarterly. An alternative measure of the effect of timeliness is FAA data on percent of flights that arrived on time. This was first available in 1987, and is available for only 10 of the carriers in the original sample.

The specification of inputs and characteristics is the same in both cases; inputs: labor, energy, materials, long and short haul measures of capacity; characteristics: stage length, load factor, average size, average age and fuel index. Outputs include passenger revenue miles and non revenue miles. The circuity index is our first measure of inconvenience or undesirable aspects of the carrier on average. Descriptive statistics are included in Table 1.

Next we estimated productivity with (LUENC)and without (LUEN) the circuity index for each of the carriers in our sample as well as with the FAA percent on time variable (LUENOT) as an alternative to our circuity measure. Sample means are summarized in Table 2. The means suggest that in all cases there has been a small decline in productivity for our sample over this time period. The model using the ontime variable exhibits the greatest decline on average, followed by the circuity model. The model which does not account for these characteristics yields average productivity growth that is above the alternate models, as we would expect. Based on a simple t-test, the difference in the means is significant between the on time and no bads model and between the circuity and on time models, but not between the circuity and no bads model.

6 Summary

In this paper we provide an overview of some approaches to modeling and measuring productivity in the presence of joint production of desirable and undesirable outputs. These have in common an axiomatic production theoretic framework, in which joint production is explicitly modeled using the notion of null-jointness proposed by Shephard and Färe, and weak disposability of outputs is imposed to model the fact that reduction of bad outputs may be costly.

In measuring productivity in the presence of undesirable outputs, traditional growth accounting and index number approaches face the problem that prices of the undesirable outputs typically do not exist since such outputs are generally not marketed. An alternative which does not require price information is the Malmquist productivity index which is based on ratios of Shephard type distance functions. These do not require information on prices, which suggests that they would be an appropriate methodological tool. Although an improvement over ignoring undesirable outputs, the Malmquist index computed with bads may not have well-defined solutions, and, it effectively registers increases in the bads (like the goods), ceteris paribus as improvements in productivity.

In order to address these problems we employ an alternative measure of TFP based on a generalization of the Shephard distance functions, namely what we call directional output distance functions. Not only are these distance functions generally computable in the presence of undesirable outputs, but they also allow us to 'credit' firms for *reductions* in undesirable outputs, while crediting them for *increases* in good outputs. The Luenberger productivity indicator is constructed from directional distance functions, but in contrast to the Malmquist index, it has an additive structure. Both are easily computable using linear programming techniques very similar to traditional data envelopment analysis.

In our application to US airlines, we find that accounting for characteristics such as circuity or percentage of flights arriving on time does affect productivity, yielding, in general lower rates of productivity growth in our sample.

Table 1

Descriptive Statistics: Model Variables (N=670)

Measure	Mean	St. Dev.	Min	Max
Labor	93695379.70	68740119.68	1114600.00	289780000
Energy	27086136.87	20109437.64	1804700.00	94679000.00
Materials	85083888.21	71986598.27	5617000.00	293930000
Short haul	169.45	104.10	28.33	457.30
Long Haul	53.23	57.83	0	243.68
Pass. Rev. Miles	495440704	421930553	20661000.00	2006800000
Non Rev Miles	57112070.39	59930926.44	547330.00	243870000
CIRC	0.00003	0.001	8.42E-7	0.02
Stage Length	616.97	222.38	203.89	1626.40
Load Factor	0.60	0.06	0.44	0.77
AVE. Size	179.31	46.27	8.05	262.88
AVE Age	188.79	25.50	128.88	863.45
FUEL Index	0.31	0.07	0.19	1.06

Table 2

Descriptive Statistics: Productivity Change (N=326)

Measure	Mean	St. Dev.	Min	Max
LUEN (no bads)	-0.00085	0.02732	-0.08750	0.08262
LUENC (circularity)	-0.00137	0.03250	-0.19460	0.16461
LUENOT (on time)	-0.00484	0.01864	-0.07760	0.08631
LUENC-LUEN	-0.0005	0.01659	-0.10710	0.15338
LUENOT-LUEN**	-0.0040	0.03255	-0.07864	0.09045
LUENC-LUENOT*	0.0035	0.03701	-0.19390	0.18481

* (**)significantly different from zero at 10 (5)% level

7 Figures

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 2: Figure 6

8 References

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