Multifactor productivity change in the air transportation industry

Productivity increases in the U.S. airline industry—the Nation's primary intercity mass transportation system—have played a significant role in the industry's cost-containment efforts and its ability to accelerate growth

John Duke
and
Victor Torres

The U.S. air transportation industry is a key component of the U.S. economy. About 42 percent of all passenger trips with roundtrip distances of between 1,000 and 1,999 miles are taken by plane. This percentage increases dramatically to 75 percent if the roundtrip distance is at least 2,000 miles.[1] Advances in technology that led to the development of modern jets, along with the Airline Deregulation Act enacted by Congress in 1978, have allowed the U.S. airline industry to become the primary intercity mass transportation system in this country. The air transportation industry is important to our national economy, but it faces unprecedented challenges.[2] The economic downturn that began in early 2001 and the terrorist attacks of September 11, 2001, led to reduced demand for air travel thereby resulting in decreased profitability or losses for many companies.[3] These trends highlight the importance of controlling costs in the industry, and over the last three decades, productivity has played a significant role in the industry's ability to control costs and to accelerate growth.

For many years, the Bureau of Labor Statistics (BLS) has published a measure of labor productivity for air transportation. This article discusses and analyzes a new BLS measure of multifactor productivity for the air transportation industry, coded 481 in the North American Industry Classification System (NAICS), covering the period 1972 to 2001. This measure is consistent with the new definition of the air transportation industry under NAICS in which air couriers are no longer included in air transportation, but classified in NAICS 4921, couriers, instead.

Labor productivity relates output to the labor resources used in its production. It is an indicator of the efficiency with which labor is being utilized, an important indicator of economic progress. Despite its widespread use, a labor productivity measure should not be interpreted as representing only the contribution of labor to production. Changes in output per hour (or productivity) reflect a wide range of influences, including changes in technology, skill and effort of the workforce, organization of production, economies of scale, and the amount of capital per hour and intermediate purchases per hour. Labor productivity is a frequently used measure of economic performance. It is recognized by researchers as an important tool for monitoring the health of the economy. Over time, growth in real per capita income and increases in living standards tend to follow growth in labor productivity. Higher productivity growth increases the competitiveness of a business, industry, or nation. Moreover, labor productivity serves as a buffer against higher labor costs by offsetting part or all of the growth in compensation per hour.

Whereas labor productivity relates the change in output to the change in one input—labor—multifactor productivity relates the change in output to the change in a combination of inputs. Growth in multifactor productivity can be seen as a measure of economic progress; it measures the increase in output over and above the gain due to increases in a combination of inputs. The combined inputs measure is a weighted average

John Duke is a supervisory economist, and Victor Torres is an economist, in the Division of Industry Productivity Studies, Office of Productivity and Technology, Bureau of Labor Statistics; Paul Kern, formerly with the same office, also contributed to the calculation of the measures presented here.
E-mail:
Duke.John@bls.gov
Torres.Victor@bls.gov

of labor hours, capital services, and intermediate purchases.[4] The weights represent each input's share in the total cost of output. Although the amount and complexity of the data required to calculate a measure of multifactor productivity are much greater than those for a labor productivity series, a multifactor productivity measure yields valuable insights into efficiency beyond those derived from a labor productivity measure. For example, in air transportation, the expansion in the stock of *widebody* fleet in the mid-1970s seems to be behind the productivity increase that is unrelated to load factors.[5] Similarly, because energy costs comprise a large part of intermediate purchases, "…the omission of this input component would seriously degrade the true measure of productivity trends."[6] Multifactor productivity reflects many of the same influences as the labor productivity measure, but by explicitly accounting for inputs of capital and intermediate purchases, the multifactor productivity residual reflects only changes in overall efficiency that are due to other unmeasured influences.

This article describes the patterns of multifactor productivity and labor productivity change in air transportation since 1972 and the sources of labor productivity change—namely, changes in multifactor productivity, capital intensity, and intermediate purchases intensity. It looks behind the aggregate data to describe output and the use of the productive factors—labor, capital, and intermediates—in this industry and how they have changed over time. The current situation in the industry is briefly discussed.

Overview of productivity change

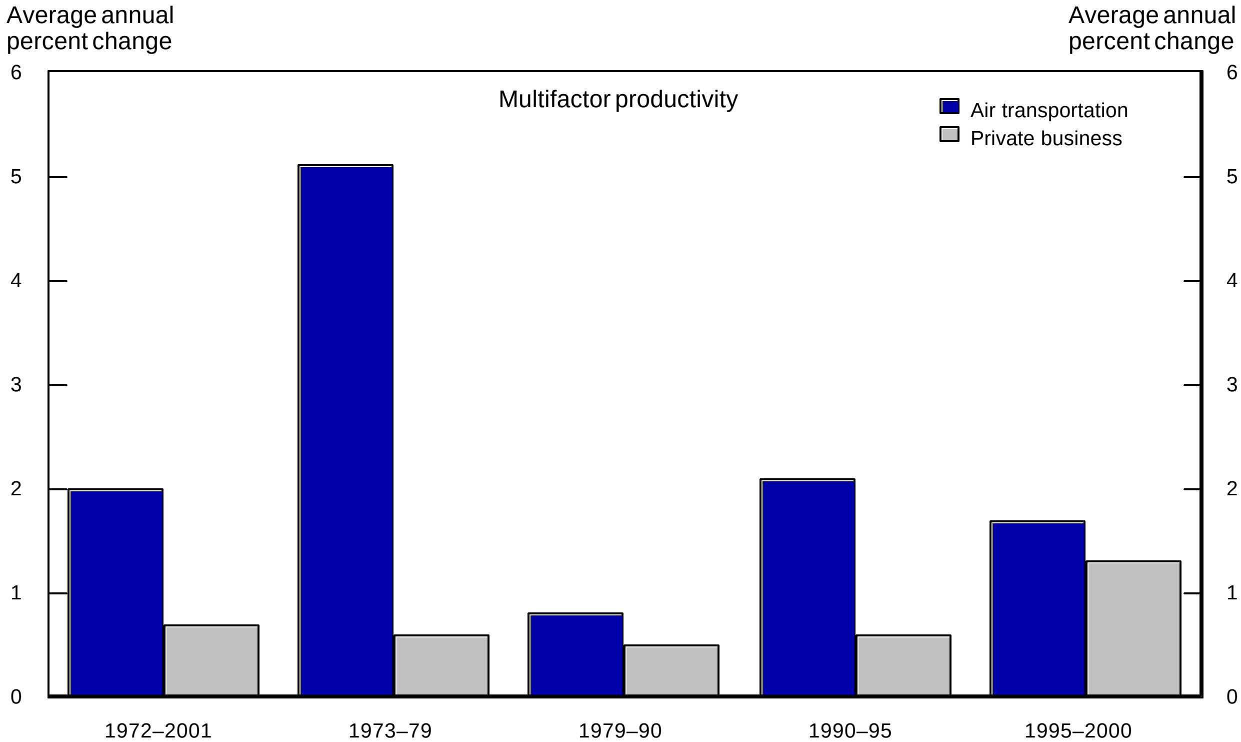
Productivity trends in air transportation and the private business sector. Multifactor productivity in the air transportation industry increased at an average annual rate of 2.0 percent over the 1972–2001 period, almost triple the 0.7-percent rate for the private business sector as a whole (see chart 1). The labor productivity growth rates were not nearly as different, at 2.4 percent per year for air transportation and 1.7 percent for the private business sector. Multifactor productivity in air transportation decelerated from a very high average annual gain of 5.1 percent during the 1973–79 period to a 0.8-percent gain from 1979 to 1990, and it rebounded back to a 2.1-percent growth rate during the first half of the 1990s. The growth rate in labor productivity followed a similar pattern, dropping from an average of 5.6 percent during the first period to 1.6 percent during the second period, and increasing to a 4.2-percent average annual growth rate during the early 1990s. This was a very different pattern of productivity growth than that of the private business sector. Multifactor productivity in the private business sector showed almost identical growth rates in the 1973–79, 1979–90, and 1990–95 periods (0.6 percent, 0.5 percent, and 0.6 percent, respectively). It then accelerated to 1.3 percent from 1995 to 2000. The 1990–2000 period, which represents a complete business cycle, is broken into two sub-periods to highlight the widely-noted business sector productivity speedup in the last half of the 1990s. The airline industry, however, did not experience a productivity speedup in either labor productivity or multifactor productivity from the first half of the 1990s to the second half.

A substantial part of the labor productivity speedup in the private business sector during the late 1990s can be attributed to the effects of improvements in the use of information processing equipment and software (IPES) capital. Unfortunately, the data do not permit separating out IPES capital for airlines. The contribution of capital intensity as a whole is small for airlines, with an increase of only 0.2 percent per year over the entire 1972–2001 period and no growth in capital's effect from 1995 to 2000.

In 2001, multifactor productivity in the air transportation industry experienced a large decline of 4.2 percent (see table 1). Labor productivity also declined at a substantial 6.4-percent rate, the largest decline over the period studied in this article. Output dropped 6.6 percent, while combined inputs fell only 2.5 percent. A recession occurred from the first quarter to the fourth quarter of 2001, and multifactor productivity in the private business sector declined also, although labor productivity increased. Both labor productivity and multifactor productivity for airline transportation declined in previous years around recessions (1980, 1981, and 1990 or 1991)—but the 2001 declines were the largest and second largest, respectively. Airlines in 2001 also were strongly affected by the events of September 11. Data for 2001 from the Air Transport Association of America (ATA) indicate that airline traffic grew a modest 2.8 percent in the first quarter, with no change during the second quarter.[7] After the terrorist attacks, however, operations were completely shut down for 4 days.[8] Air travel fell dramatically thereafter, resulting in declines of 7.8 percent and 19.0 percent for the third and fourth quarters, respectively.[9] Overall, the September 11 attacks, along with the economic recession that began in March 2001, caused a reduction in domestic airline capacity—obtained by multiplying the number of seats available for sale by the number of miles flown—of 3.0 percent in 2001.[10] Labor productivity rebounded (up 12.2 percent) in 2002. Labor hours were reduced by 11.6 percent, but output fell only 0.8 percent. Data for multifactor productivity, capital input, and intermediate purchases input are not yet available for 2002.

The sources of growth in labor productivity. Labor productivity growth can be decomposed into multifactor productivity growth plus the effects of changes in capital and intermediate purchase

Chart 1. Labor productivity and multifactor productivity for the private business sector and air transportation, 1972–2001 and selected periods



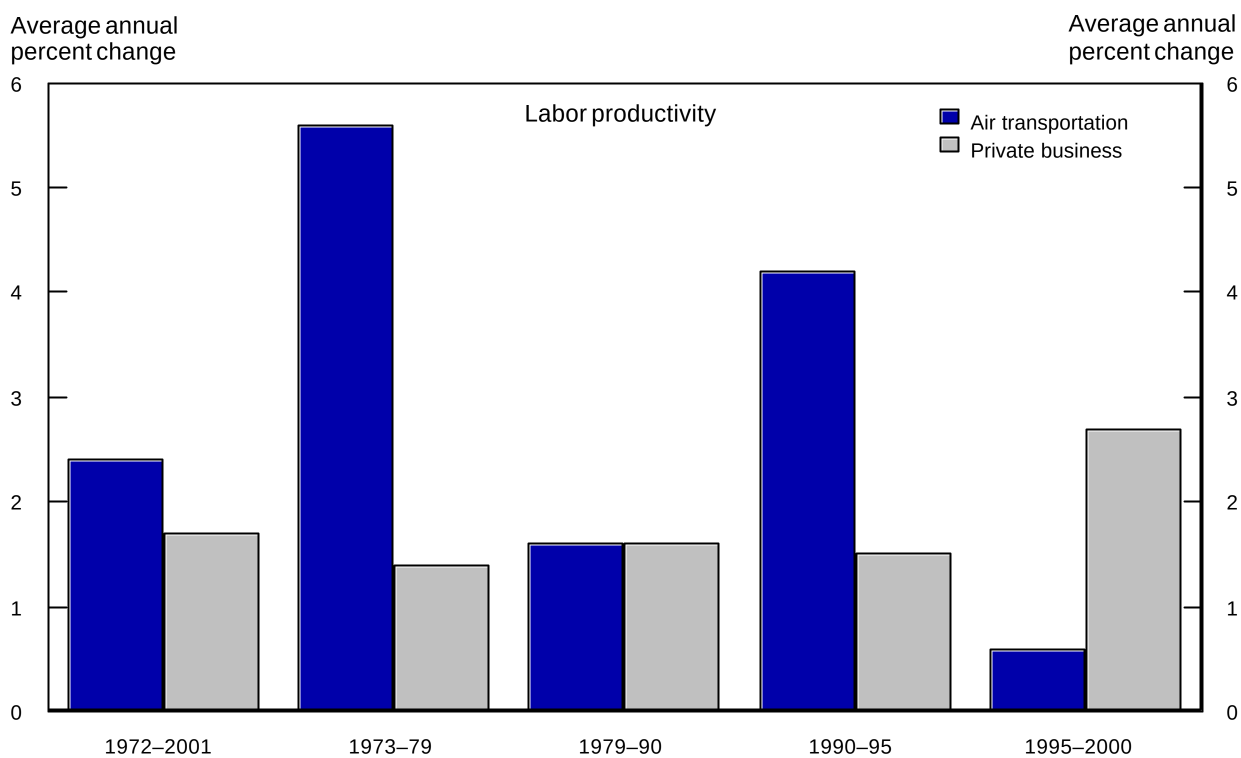


Table 1. Percent changes in output per hour, multifactor productivity, and related measures for air transportation, 1972–2001

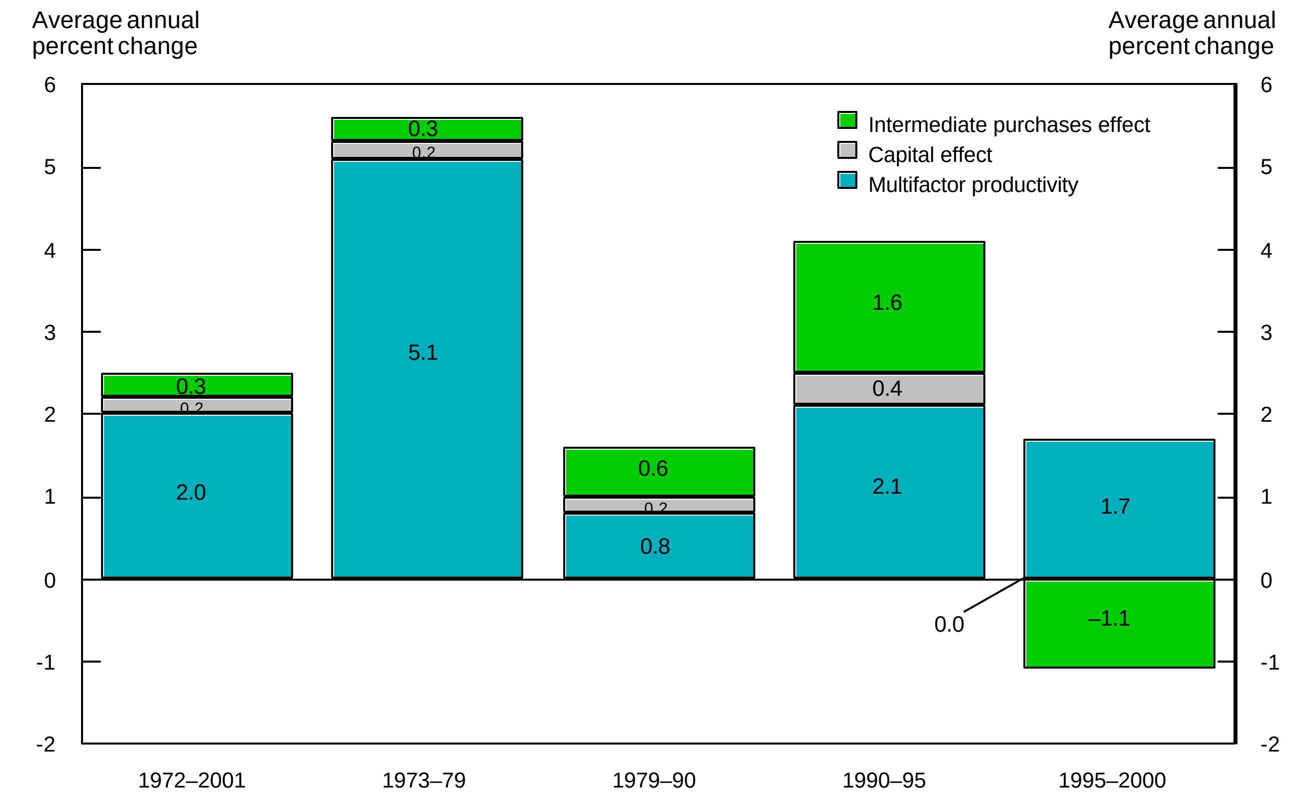
Year	Output per hour	Output	Hours[1]	Multifactor productivity	Combined inputs	Capital	Intermediate purchases	Output per unit of capital	Output per unit of intermediate purchases
1973	2.0	5.9	3.9	2.1	3.8	4.5	3.3	1.4	2.5
1974	1.3	0.3	–1.0	1.3	–1.0	5.7	–3.1	–5.1	3.5
1975	1.0	–0.7	–1.7	1.2	–1.9	5.8	–3.4	–6.1	2.8
1976	8.9	10.1	1.1	6.9	3.0	2.7	5.2	7.2	4.6
1977	4.7	7.4	2.6	4.2	3.1	0.3	4.2	7.1	3.1
1978	9.5	14.0	4.1	9.5	4.1	2.4	4.4	11.4	9.2
1979	8.8	15.8	6.4	8.0	7.2	4.3	8.8	11.0	6.4
1980	–6.2	–3.6	2.8	–6.0	2.6	3.2	2.3	–6.6	–5.8
1981	–0.6	–2.2	–1.6	–0.5	–1.6	2.8	–2.2	–4.8	0.0
1982	10.4	4.4	–5.4	7.6	–3.0	–0.2	–1.5	4.6	6.0
1983	10.0	8.2	–1.7	6.8	1.2	–0.1	3.6	8.3	4.4
1984	3.9	8.7	4.6	0.9	7.7	4.0	10.8	4.5	–2.0
1985	3.6	8.9	5.1	2.1	6.6	8.0	7.4	0.8	1.4
1986	2.0	9.9	7.8	–1.4	11.4	11.8	14.1	–1.7	–3.7
1987	0.1	10.5	10.4	1.5	8.9	11.4	7.4	–0.8	2.9
1988	0.6	4.6	3.9	0.3	4.2	6.8	3.8	–2.1	0.7
1989	–2.9	1.2	4.2	–2.1	3.3	5.5	2.0	–4.1	–0.9
1990	–2.1	3.7	5.9	0.8	2.9	5.9	–0.1	–2.1	3.8
1991	0.9	–2.1	–2.9	–0.1	–2.0	3.1	–2.7	–5.1	0.6
1992	4.1	6.0	1.9	3.6	2.4	–1.7	3.9	7.9	2.0
1993	4.0	3.2	–0.8	–3.0	6.4	3.9	12.6	–0.7	–8.3
1994	7.3	6.6	–0.6	6.5	0.1	6.6	–0.8	0.0	7.5
1995	5.0	4.2	–0.7	4.0	0.2	1.5	0.5	2.7	3.7
1996	3.6	6.8	3.1	3.8	2.9	2.7	2.8	4.0	3.9
1997	1.2	4.4	3.2	1.1	3.3	3.0	3.5	1.4	0.9
1998	–2.4	2.2	4.8	–1.0	3.2	4.5	1.7	–2.1	0.5
1999	0.7	5.0	4.3	1.8	3.1	4.5	1.8	0.5	3.1
2000	0.0	6.1	6.1	3.0	3.0	5.9	–0.2	0.2	6.3
2001	–6.4	–6.6	–0.2	–4.2	–2.5	4.5	–5.5	–10.6	–1.1
	Average annual percent change								
1972–2001	2.4	4.8	2.3	2.0	2.8	4.2	2.8	0.6	1.9
1973–79	5.6	7.6	1.9	5.1	2.4	3.5	2.6	4.0	4.9
1979–90	1.6	4.8	3.2	0.8	3.9	5.3	4.2	–0.5	0.6
1990–2000	2.4	4.2	1.8	1.9	2.2	3.4	2.2	0.8	1.9
1990–95	4.2	3.5	–0.7	2.1	1.4	2.6	2.6	0.9	1.0
1995–2000	0.6	4.9	4.3	1.7	3.1	4.1	1.9	0.8	2.9

[1] Average weekly hours were assumed to be constant at 40 due to lack of adequate data.

inputs relative to labor. The influence of capital on labor productivity is referred to as the "capital effect," which is measured as the rate of change in the capital-labor ratio multiplied by the share of capital costs in total output cost. Similarly, the influence of intermediate purchases on labor productivity is referred to as the "intermediate purchases effect," and is measured as the rate of change in the intermediate purchases-labor ratio multiplied by the intermediate purchases' share in total output cost.

Chart 2 shows labor productivity in air transportation and its decomposition into the capital effect, the intermediate purchases effect, and multifactor productivity for the 1972–2001 period and several sub-periods. Among these three components of labor productivity change, the largest contributor during the overall 1972–2001 period was multifactor productivity, accounting for more than 80 percent (2.0 percentage points) of the 2.4-percent average annual growth rate in labor productivity. The effects of capital and intermediate purchases accounted for the difference, each contributing about one-half of the remaining change in labor productivity—0.2 and 0.3 percentage points, respectively—over the period.

Chart 2. Sources of labor productivity growth for air transportation, 1972–2001 and selected periods



NOTE: Labor productivity may not be equal to multifactor productivity plus the effects of changes in the capital and intermediate purchase inputs relative to labor, due to rounding.

The average annual growth rate in the capital effect remained at 0.2 percent during the first two periods. It then increased to 0.4 percent in the early 1990s but fell back to no growth during the 1995–2000 period. The intermediate purchases effect was modest in both the 1973–79 and the 1979–90 periods, although it rose from an increase of 0.3 percent to a rise of 0.6 percent. It then jumped to an average gain of 1.6 percent per year in the early 1990s but fell by 1.1 percent in the late 1990s.

Output

Changes in output in the air transportation industry respond to many factors, including Federal legislation, competition among the airlines, and the increasing influence that regional jets are having on air travel, particularly among business travelers who account for 70 percent of regional jet passengers.[11] The general state of the economy also plays a role. As evidenced by recent events, output also can be affected by fears of air travel due to terrorism, health issues such as the 2002 outbreak of severe acute respiratory syndrome (SARS), and international conflicts such as the war in Iraq.

Output in the airline industry is comprised of passenger services, as measured by passenger miles, and cargo services, as measured by ton-miles. (See the appendix.) Passenger miles is by far the largest component, making up more than 90 percent of total revenue, with the remainder attributable to ton-miles. Although the output measure does not account for changes in service quality such as flight delays and route circuitry, some recent studies seem to indicate that such changes did not significantly affect output and productivity.[12]

Real output in the air transportation industry almost quadrupled over the 1972–2001 period, an average annual gain of 4.8 percent, compared with a 3.4-percent average annual increase in the private business sector. Output in the airline industry exhibited a cyclical pattern, although it also has been influenced by factors other than the business cycle. From 1973 to 1979, output expanded at an average of 7.6 percent per year. This rapid growth in output, however, masks considerable variation during the period. For example, from 1973 to 1975, the air transportation industry struggled as the fuel crisis, and a continuing economic recession, hit hard throughout the economy; output actually declined 0.3 percent per year during this sub-period.

From 1975 to 1979, an upturn in the Nation's economy and industry deregulation (1978) led to a resurgence of traffic growth, and output accelerated to an impressive average annual growth of 11.8 percent per year. The industry set new traffic records in 1978 and 1979, as output increased 14.0 and 15.8 percent, respectively. Under deregulation—which allowed changes in routes and fares, and the formation of new airlines—price competition, route restructuring, and new airline formation became driving forces in the reduction of operator costs. Airlines made changes to increase the efficiency of their operations. For example, under government regulation, airlines were forced to fly directly to remote or small markets, often with nearly empty flights.[13] Although convenient for the few who lived in those areas, this proved to be very inefficient for the carriers, given that the cost to fly a plane is about the same whether it is empty or full. Therefore, deregulation led to the development of widespread hub-and-spoke networks.[14] This allowed the airlines to serve many more markets than they otherwise could, with the same number of planes, if they offered only point-to-point flights.[15]

Under regulation, with price competition restricted, airlines often engaged in competition based on the level and quality of service. This resulted in overuse of labor and materials inputs.[16] With the new hub-and-spoke networks, the airlines could achieve higher load factors in the smaller markets, which could result in lower operating costs and lower fares. "According to one respected source, deregulation was responsible for 58 percent of the price cuts from 1978 to 1993 and made fares 22 percent lower than they would have been without deregulation."[17]

From 1979 to 1990, output in the air transportation industry expanded at 4.8 percent per year on average. The overall growth rate in output for this period also obscures some variability in the interim years, although not as pronounced as that during the 1973–79 period. For example, the inflation, soaring fuel prices, and the general economic situation facing the United States from 1979 to 1981 yielded output declines of 3.6 percent and 2.2 percent in 1980 and 1981, respectively. In fact, in 1980 the industry recorded the sharpest drop in traffic in more than 50 years of scheduled air transportation.[18] In 1982, the decline in passenger traffic began to reverse, and output managed to accelerate rapidly to an annual average of 8.0 percent from 1981 to 1986. The commercial airline industry set passenger traffic records, year after year, during the last 4 years of this period (1982 to 1986).[19] The demand for air cargo services also grew significantly from 1981 to 1986, with records set during 3 of the 5 years. In 1987, the demand for commercial air transportation continued its growth, as new records were set for passengers, revenues, employment, and aircraft on order.[20] Overall, output posted a rise of 4.9 percent per year during the 1986–90 period.

For the overall 1990–2000 decade, output grew an average of 4.2 percent per year, climbing by 3.5 percent during the first half of the period (1990–95), and accelerating slightly to 4.9 percent during the second half (1995–2000). Output in the airline industry declined in 2001. Prior to September 11, average domestic airfares had already fallen sharply in response to the weakening economy, reduced business travel, and an increasing proportion of low-margin leisure travelers.[21] The September 11, 2001, terrorist attacks further exacerbated a weakened air transportation industry by forcing it to briefly shut down its operations. The airlines cut capacity over the last 4 months of 2001, although the month-to-month reductions in capacity slowed from a high of 19 percent in September to 10 percent in December.[22] Output for 2002 as a whole declined slightly, by 0.8 percent, from 2001.

Inputs

Labor. Employment in the air transportation industry almost doubled from 294,600 in 1972 to 575,500 in 2001.[23] During the same time period, output almost quadrupled. Between 1973 and 1979, employment increased relatively slowly at an average annual growth rate of 1.9 percent, although output expanded at a rapid 7.6 percent per year. After the Airline Deregulation Act of 1978, however, the industry went through a period of adjustment. By 1984, the number of scheduled interstate carriers had increased from 36 to 123, providing a variety of competitive options to air travelers and shippers.[24] The entry of these new carriers into the industry put downward pressure on fares and strongly contributed to a 3.2-percent average annual employment increase from 1979 to 1990, as output climbed 4.8 percent. During the 1990–2000 decade, employment growth in the air transportation industry slowed markedly to an average 1.8 percent per year. Employment declined by a slight 0.2 percent in 2001, then dropped a substantial 11.6 percent in 2002. Part of the slowdown in the 1990s was spurred by increased customer use of Internet Web sites for air travel planning. These Web pages have grown increasingly more sophisticated, allowing travelers to do almost everything related to their travel, from checking the status of their frequent-flyer accounts, to booking flights and selecting their own seats. With this increased Internet use by customers, airlines have been able to reduce the number of customer service agents needed to handle bookings and flight information questions. In addition to being able to book their own flights, once travelers arrive at the airports across the country, they can take advantage of the self-service kiosks provided by the airlines, which have grown in popularity since their introduction in 1995. These kiosks allow the passengers to get boarding passes for originating or connecting flights; select seats; request to stand by for an upgrade; check baggage; and change flights, among other things.[25] The increased use of self-service kiosks has given airline carriers the flexibility to lower their costs by using fewer customer service agents at the airports.

Although flight crew members, which include pilots and flight attendants, are highly visible employees in the airline industry, they comprise only about 30 percent of total employment.[26] The majority of employees in the industry work in "ground occupations." In addition to reservation and transportation ticket agents and customer service representatives, their occupations include aircraft mechanics, service technicians, and baggage handlers, among others.

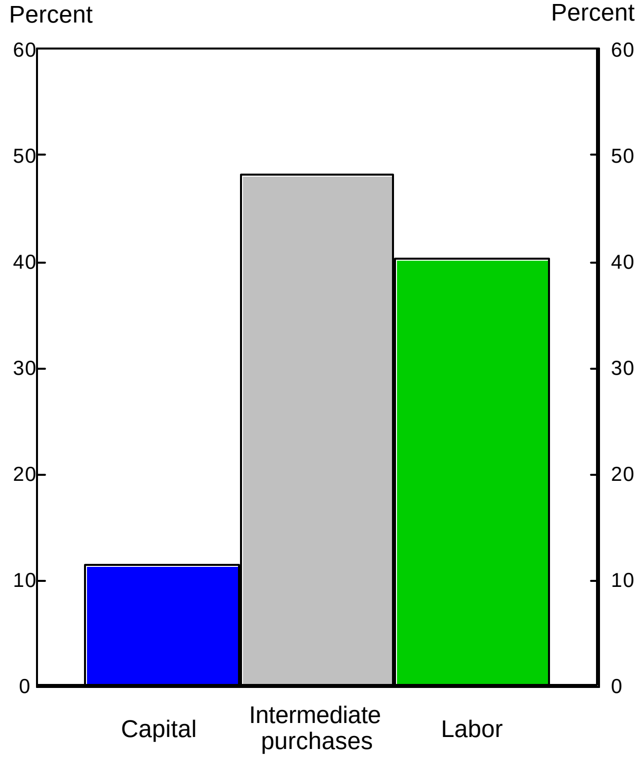
Capital services. The air transportation industry requires a large amount of physical capital in order to provide services. Because most capital equipment is financed through loans or the issuance of stock, establishments in this industry need to maintain healthy levels of profits and cash flows to meet their debt obligations or to acquire, through leases or purchases, aircraft and other capital equipment. The capital measure consists of the flow of services provided by these capital goods, which include items such as aircraft, engines, food service equipment, baggage handling equipment, computers, ticket and boarding pass issuing and reading equipment, and other ground equipment.

The air transportation industry has experienced rapid growth since its origins dating back to the Contract Air Mail Act of 1925, and this growth has been accompanied by growth in the quantity and complexity of the capital stock. A number of important technological innovations—before and during regulation—made airplanes safer, faster, and more efficient, helping to attract passengers away from other means of transportation such as railroads. The 1938 Civil Aeronautics Act, which helped maintain order in the industry, "…coupled with the tremendous progress made on the technological side, put the industry firmly on the road to success."[27] Moreover, during WWII, new technologies such as the gas turbine engine revolutionized the air transportation industry and laid the groundwork for a tradition of continued technological change in the decade that followed.[28] The new technologies that were available entering the post-WWII period, coupled with the extensive engineering and flying skills developed during the war—and the resulting production facilities that existed—created an increased public acceptance for air travel.[29] As air travel soared following the war, the skies got more crowded and safety became a serious issue, prompting Congress to create the Federal Aviation Agency in 1958 (predecessor to the Federal Aviation Administration). The new agency was in charge of establishing and running an air traffic control system, as well as overseeing all other aviation safety matters. The 1950s also saw important innovations in airport and airway technologies such as Instrument Landing Systems (ILS), approach lighting systems, and the navigational aid VORTAC (VHF Omni directional Range with Tactical Air Navigation), which transmits a signal allowing an aircraft to determine its bearing.[30] In the 1960s, all major airlines were replacing their aging piston-engine types with jet aircraft. "Boeing 707s, DC8s, Convair 880s and VC10s replaced the earlier DC7s, Stratocruisers, and Constellations on the long-haul routes. Boeing 727s, Caravelles, DC9s, BAC111s and Tridents replaced the piston-twin types on medium and short-haul routes."[31] The introduction of these jet aircraft sharply reduced the time and cost of transporting passengers and freight. According to a study by Robert Gordon, labor productivity in the commercial airline industry increased at an average annual rate of 7 percent during the 1960s, which was significantly higher than that of the U.S. economy as a whole.[32]

Between 1972 and 2001, the flow of services from capital stock increased rapidly at an average annual rate of 4.2 percent. This growth rate is consistent with a rapid output growth of 4.8 percent per year. Over the same period, the cost of capital services averaged 11.5 percent of total costs (see chart 3.) The share in total costs comprised by capital may seem low. However, airline assets have long service lives; therefore, replacement costs per dollar of stocks are lower than in most other industries. In addition, some "capital" such as airport terminal space is rented and counted in intermediate purchases rather than in capital, although this is not the case for leased aircraft, which are included in the capital input measure. By 2001, capital input had more than tripled from the 1972 level.

Growth in capital input accelerated from a 3.5-percent average annual rise during the 1973–79 period to a 5.3-percent average annual gain from 1979 to 1990. This increase in the growth rate of capital occurred despite a falloff in the growth of output, which dropped from an average increase of 7.6 percent in the first period, to 4.8 percent in the latter period. During the 1970s decade, *widebody* 'Jumbo' jets—such as Boeing 747s, Douglas DC10s, and Lockheed L1011 Tristars—were introduced into service. With their very large size, the jumbo jets provided economies of scale that allowed for more travelers to fly for a lower cost. The Boeing 747, for example, could seat as many as 490 passengers and reach speeds of up to 604 miles per hour.[33] As the number of jumbo jets in the industry increased in the mid-1970s, the productivity gains that were not related to load factors seem to have been significantly influenced by the expansion of this fleet of large capacity airplanes.[34] The 1970s also saw the introduction of the second generation of jet airliners, such as Airbus'

Chart 3. Input cost shares for air transportation, 1972–2001



A300-600 and Boeing's 737-100 and 200, for medium and short haul routes. The A300-600, a medium range widebody airliner, featured a two-crew EFIS (Electronic Flight Instrument Systems) cockpit, with digital avionics.[35] During the 1980s, new aircraft were introduced with more powerful but quieter engines. For example, the Boeing 737-300, 737-400, and 737-500—with the CFM56 engine (made by General Electric/Snecma)—were produced.

Other airliners that entered the industry in the 1980s include Boeing's 757 and 767, which were developed in tandem and share a number of systems and technologies—including a common early-generation EFIS flightdeck that integrated the functions of dozens of separate instruments to simplify cockpit scan, thus reducing pilot workload and fatigue. Since their introduction, the evolution of EFIS systems have allowed operators to benefit from more capability, flexibility, and redundancy with increased reliability.[36] Airbus introduced the A310 and the A320. The A320, a short to medium range airliner, is the first plane to introduce a fly-by-wire flight control system, under which control inputs from the pilot are signals rather than mechanical processes.[37] A fly-by-wire system is built to interpret the pilot's *intention* and translate it into action, a translation process that takes environmental factors into account first.[38] The advantage of this type of system is that it is computer-controlled, making it virtually impossible to exceed certain parameters such as G limits and maximum and minimum operating speeds.

The flow of services from the capital stock fell to an average annual rise of 3.4 percent during the 1990–2000 decade, as output continued to expand by 4.2 percent per year. In 2001, capital input increased 4.5 percent, while output declined 6.6 percent. The most noteworthy commercial aircraft introduced in the United States in the 1990s were those in the Boeing 777 jetliner family. "Notable 777 design features include a unique fuselage cross section, Boeing's first application of fly-by-wire, an advanced technology glass flightdeck with five liquid crystal displays, comparatively large scale use of composites (10% by weight), and advanced and extremely powerful engines."[39] It was designed as a replacement for the early generation 747s; and although their passenger capacities are comparable, it burns one-third less fuel, and it features 40-percent lower maintenance costs. The development of large turbofan (fuel-efficient) engines during the 1990s is particularly important for airline establishments, given that fuel represents their second largest expense, exceeded only by labor. The Boeing 777-300 can seat up to 550 passengers in a single-class high-density configuration.

A closer look at the 1990–2000 period shows that during the first half of the decade (1990–95), capital services grew at a moderate rate, increasing by an average of 2.6 percent per year, while output maintained a moderate growth of 3.5 percent. During the 1990–91 period, the United States was experiencing a recession, coupled with the conflict in the Persian Gulf. In 1991 alone, the air transportation industry experienced an output decline of 2.1 percent, the largest in a decade, along with a 2.9-percent drop in employment. The industry recorded an employment decline of 0.7 percent per year, on average, during the entire 1990–95 period. The economic downturn that led to financial losses in 4 of the 5 years between 1990 and 1995 caused the air transportation industry to accumulate debt and to scale back on capital acquisitions. The industry was faced with the difficult task of meeting its capital needs as it tried to replace its oldest, noisiest jets with newer environmentally-friendly technology.[40] In 1995, the commercial airline industry began to recover financially and posted its first net profit after 5 years of losses. During the second half of the decade (1995–2000), the growth rate in capital services in the air transportation industry rebounded to an annual average of 4.1 percent, as output grew rapidly at 4.9 percent per year. The industry experienced net operating profits every year during this period.

Intermediate purchases. Intermediate purchases include the materials, fuels, electricity, and purchased services used in the production of the industry's output. Purchases of intermediate materials grew by 2.8 percent per year from 1972 to 2001. Intermediate purchases grew moderately at an average annual rate of 2.6 percent from 1973 to 1979, then accelerated to an average annual rise of 4.2 percent in the 1979–90 period. Growth in intermediate purchases dropped again to 2.2 percent per year during the 1990–2000 decade, however. Intermediate purchases declined 5.5 percent in 2001.

From 1972 to 2001, intermediate purchase costs averaged 48 percent of the total cost of inputs (see chart 3), the largest share of the three inputs for the air transportation industry. Among intermediates, fuel is the largest component. "The major U.S. airlines spend more than $10 billion a year on fuel, which is approximately 10 percent of total operating expenses."[41] Fuel costs fluctuated greatly over the 1972–2001 period. Although fuel's share in the total cost of intermediate purchases increased only slightly, from 30 percent in 1972 to 31 percent in 2001, the small rise obscures enormous fluctuation in the interim years. Fuel's share in the total cost of intermediate purchases rose from 29 percent in 1973 to 50 percent in 1979, spurred by huge increases in the cost of fuel. The start of the enormous increases in the price of fuel coincided with OPEC's (Organization of Petroleum Exporting Countries) oil embargo that began in October of 1973.[42] By 1979, fuel made up one-half of the total cost of intermediate purchases in the air transportation industry, and almost one-fourth of total input costs; these numbers peaked in 1981 at 56 percent and 31 percent, respectively, as fuel prices continued to rise during the 1979–81 period.

As a result of the increases in fuel prices, the airline industry began to take measures such as lowering cruise speeds, using computers to determine the optimum fuel loads, and using flight simulators instead of aircraft to train pilots, among other things. In addition, the industry began to invest "…billions of dollars in new aircraft and engines that are far more efficient than the models they replace."[43] By 1989, fuel's share in the total cost of intermediate purchases had dropped to 28 percent; it then jumped again to 34 percent in 1990, when the Persian Gulf crisis began, and dropped to a low of 23 percent in 1998. Lately, some of the airlines have also begun to hedge their fuel costs by entering into agreements with their suppliers or by participating in the futures market.

Travel agent commissions, which have declined in recent years, are another type of intermediate purchase. Until recently, travel agents distributed 70 percent to 80 percent of tickets in the air transportation industry. This proportion has been declining, however, due to a changing operating environment in which air carriers are reducing commissions while Internet competition is growing.[44] Commissions paid out by establishments to travel agents followed an upward trend from 1972 to 1993. Travel agent commissions rose 6.0 percent in 1993, when their share in the total cost of intermediate purchases peaked at 22 percent. At one point, the airlines even began to offer "override" commissions in addition to the standard commission rate. Overrides are bonuses over and above the regular commission if a travel agent sends extra travelers on a particular airline.[45] For years, the airlines have been trying to reduce the travel agent commission, one of the easiest operating costs to control in the air transportation industry. The airlines have been reducing base commissions and capping dollar amounts paid out to travel agents.[46]

The 1990s also brought important developments in computer-based technology—and the Internet in particular—which played an important role in the air transportation industry's distribution process. For instance, since 1995, airlines have featured their own Web sites on the World Wide Web. In addition to the airlines' own Web site, there are third-party online outlets that specialize in online travel bookings. Many airlines have joined an online travel site originally created by four carriers in 1999, which has significantly increased the level of competition in the online travel industry. This site offers lower fares than its competitors because it eliminates the commissions that are paid out to travel agents, which can add up to 5 percent of the fare.[47]

Normally, because of a lack of detail on the types of assets being leased, leased capital is included as part of the intermediate purchases when measuring multifactor productivity for other industries published by BLS. Due to its long history of government regulation, however, the air transportation industry has kept very reliable data on leased aircraft. Therefore, leased aircraft for this industry are counted in the capital measure. Nonetheless, rentals other than aircraft leasing—which are about 40 percent of total rentals—are another important component of intermediate purchases in the airline industry. Examples of rentals that remain in the intermediate purchases input of the air transportation industry include ticket counter and baggage claim space in airports, among other things.

As of 2001, fuel, non-aircraft rentals, and total commissions—97 percent of which are paid out to travel agents—accounted for almost one-half (47.3 percent) of the total cost of intermediate purchases. Of the total cost of intermediate purchases, other services and outside flight equipment maintenance accounted for 19 percent and 8.3 percent, respectively, while passenger food and maintenance materials represented 5.9 percent and 5.4 percent, respectively. The remainder (14.1 percent) was attributable to landing fees, communication, other materials, advertising, and insurance.

Recent technological developments

Over the last decade, new technology has been developed that has the potential to greatly improve the handling of air traffic. Satellite-based technology revolutionized navigation and air-ground communications in the air transportation industry during the 1990s. The development of Global Navigation Satellite Systems such as GPS (Global Positioning System) dramatically altered the operations of aircraft and the air traffic control system. GPS consists of a constellation of 24 satellites circling the earth in six separate orbits at an altitude of 11,000 miles.[48] This system allows modern aircraft to know their location to within a few tens of meters, and replaced Microwave Landing Systems (MLS) as a precision approach aid.[49] GPS is considered inaccurate, however, and too risky to be used in take-off and landing situations, during which 50 percent of all aircraft accidents occur. A variant of this technology, DGPS (differential GPS), "…uses a fixed ground station to compensate for the inaccuracy of pure, satellite-based GPS. The ground station calculates the difference between its known location and where the satellites say it is, and beams a correcting signal to incoming aircraft—allowing them to land with pinpoint accuracy."[50] Moreover, a new technology called Automatic Dependent Surveillance-Broadcast (ADS-B) developed in the 1990s allows the Air Traffic Control system to move closer toward free flight. It is said to "… improve safety, ease congestion and increase situational awareness by giving pilots and controllers reliable, real-time traffic information." In addition to being able to detect conflicting traffic, the users are able to determine the direction, the speed, and the relative altitude of the traffic, allowing them to react almost immediately to whatever changes occur in the system.[51] Although ADS-B can provide better aircraft surveillance than radar, it is certified for awareness only.[52] It has not yet been certified as a collision avoidance system, except in areas where there is no radar.[53]

Airport capacity is one of the most significant issues facing civil aviation.[54] Because building new airports can be more expensive than expanding existing facilities, more attention has been given to the latter. In addition to adding runways and taxiways, new technologies in air traffic control systems can facilitate changing departure and approach patterns. For example, ADS-B technology allows aircraft to continuously broadcast digital data link signals of their GPS position.[55] This provides access to real-time information simultaneously to air traffic controllers and flight crews.[56] Therefore, ADS-B technology can provide the ability to control aircraft without radar, which can simplify the air traffic control system without compromising safety. Moreover, this type of technology can facilitate decreased separation between aircraft, and therefore, more flexible and fuel-efficient routes. Tests show that it could have a very big impact on capacity, where the biggest gains could come "…in marginal weather conditions and at night, when the air traffic system can get bogged down as controllers cautiously build more space between planes."[57]

The current situation

Thanks to an improvement in the economy and a gradual recovery in air travel demand, the air transportation industry has begun to see signs of a recovery, after the industry's worst downturn following the September 11, 2001, terrorist attacks. Overall, the major airlines posted net losses of $7.4 billion in 2002 and $5.3 billion in 2003."[58] The major airlines, in particular, have made significant progress. As a group, they have reduced their labor and fuel costs and are slowly emerging from the effects of the recession and the lingering aftermath of the September 11 attacks. For the third quarter of 2003, for example, they increased their yield per available seat mile by lowering capacity enough to offset a slight reduction in traffic, thus producing high load factors and generating revenue. Moreover, they cut labor costs and increased labor productivity, helping to reduce their collective cost per available seat mile significantly.[59] The future of air transportation remains uncertain, however, as airlines continue to adjust to the realities of a new industry environment and once again face high fuel prices.

The industry slump of the last few years has forced major changes in air transportation. The low-cost carriers are continuing to take market share away from the hub-and-spoke, legacy carriers. The route structure of the low-cost carriers has grown large enough to provide alternatives to travelers in almost all the large markets.[60] In contrast, the mainline carriers, saddled by the higher cost of their hub-and-spoke business models, have only begun to make inroads into the restructuring of such systems. In order to effectively compete with low-cost carriers, the legacy airlines must find a way to reduce their operating costs. In addition to cost-cutting negotiations with their labor unions, some of the hub-and-spoke carriers have introduced their own low-cost subsidiaries to compete more effectively with the low-cost airlines. Many industry analysts are skeptical, however, about the effectiveness of setting up low-fare subsidiaries without resolving some of the core problems at the major airlines.[61]

For many years the network airlines have relied on business travelers to subsidize coach fares that are set marginally above production costs.[62] Recently, there has been a shift in the buying behavior of business travelers. Because of corporate budget cuts and the increased availability of discount fares online, much business travel has been re-priced. Business travelers have relied more on other means of transportation such as alternate ground travel, charters and corporate jets, low-fare carriers, and regional carriers.[63] In addition, they have increased their use of communications technology such as high-tech videoconferencing and Webcasting—prices have fallen and high-quality systems have continued to improve—as an alternative to flying.[64] The intense competitive pressures within the industry seem likely to continue in the near future. It remains to be seen how the industry's structure will evolve from the interplay of the low-cost carriers, the legacy carriers, and the latter's low-cost spin-offs. However that evolves, generating productivity gains will continue to be an important part of the industry's cost-containment efforts. □

Notes

[1] U.S. Department of Transportation, Bureau of Transportation Statistics, as reported by the 2001 National Household Travel Survey, preliminary distance file, on the Internet at **http://www.bts.gov/publications/national_household_travel_survey/highlights_of_the_2001_national_household_travel_survey/html/table_04.html**.

[2] Air Transport Association, "Air Transport 2002," p. 5., on the Internet at **http://www.airlines.org/public/publications/display1.asp?nid=916**.

[3] Kristin S. Krause, "The worst, by far," *Traffic World*, Jan. 28, 2002, p. 34.

[4] Average hours of employees in air transportation are not available, and a constant workweek of 40 hours is assumed.

[5] Robert J. Samuelson, "Economic Focus," *National Journal*, Sept. 19, 1981, p. 18.

[6] Air Transport Association, "The sources of airline productivity," August 1982, p.13.

[7] Air Transport Association, "Air Transport 2002," p. 9.

[8] Standard & Poor's, Industry Surveys-Airlines, September 26, 2002, p. 1.

[9] Air Transport Association, "Air Transport 2002," p. 9.

[10] Standard & Poor's, Industry Surveys-Airlines, March 27, 2003, p. 4.

[11] Ibid., p. 11.

[12] David H. Good, Robin C. Sickles, and Jesse C. Weiher, "A Hedonic Price Index for Airline Travel," May 21, 2001, p. 26, on the Internet at **http://www.ruf.rice.edu/~rsickles/paper/bls.pdf**; R. Färe, S. Grosskopf, and R.C. Sickles, "Productivity? of U.S. Airlines After Deregulation," September 18, 2001, p. 16, on the Internet at **http://www. http://www.ruf.rice.edu/~rsickles/paper/fgs.pdf**.

[13] Delta, "THE PLANE TRUTH," p. 4, on the Internet at **http://www.delta.com/pdfs/plane_truth.pdf**.

[14] Hubs are strategically located airports used as transfer points for passengers and cargo traveling from one community to another. They are also collection points for passengers and cargo traveling to and from the immediate region to other parts of the country or overseas.

[15] Air Transport Association, "The Airline Handbook-Online Version," Chapter 2, p. 3.

[16] David H. Good, M. Ishaq Nadiri, and Robin C. Sickles, "The Structure of Production, Technical Change and Efficiency in a Multinational Industry: An Application to U.S. Airlines," Working Paper No. 3939 (Cambridge, MA, National Bureau of Economic Research, Inc., December 1991), pp. 6, 21.

[17] William C. Goodman, "Transportation by air: job growth moderates from stellar rates," *Monthly Labor Review*, March 2000, p. 43.

[18] Air Transport Association, "Air Transport 1981," p. 1.

[19] Air Transport Association, "Air Transport 1988," p. 3.

[20] *Ibid*., p. 1.

[21] Standard & Poor's, Industry Surveys-Airlines, September 26, 2002, p. 4.

[22] *Ibid*., p. 2.

[23] Although the composition of labor input may be influenced by changes in factors such as training, experience, and education, the data used in this article treat labor input as a homogeneous factor. Thus, employees are added with no distinction made between workers with different skill levels or wages. The effects of changes in labor composition are included in the productivity residual. See labor input section in the appendix for additional information.

[24] Air Transport Association, "Air Transport 1984," p. 1.

[25] Linda Rosencrance, "Best in class: Self-service check-in kiosks give travelers more control," *Computerworld*, Feb 4, 2003, p. 48.

[26] U.S. Department of Labor, Bureau of Labor Statistics, *Career Guide to Industries*, p. 6, on the Internet at **http://www.bls.gov/oco/cg/cgs016.htm#related**.

[27] Aviation History - Aviation Resource Center, on the Internet at **http://www.geocities.com/CapeCanaveral/4294/history/index.html**.

[28] Ivan L. Pitt and John R. Norsworthy, *Economics of the U.S. Commercial Airline Industry: Productivity, Technology and Deregulation*, Kluwer Academic Publishers, 1999, p. 41.

[29] *Ibid*.

[30] Dr. Antonio A. Trani, "History of Air Transportation," on the Internet at **http://128.173.204.63/courses/cee5614/cee5614_pub/airtran_history.pdf**.

[31] Pilotfriend.com, on the Internet at **http://www.pilotfriend.com/century-of-flight/Aviation%20history/airliners/2nd%20upload/timeline%2060s1.htm**.

[32] Robert J. Gordon, "Productivity in the Transportation Sector," Working Paper No. 3815 (Cambridge, MA, National Bureau of Economic Research, Inc.), Aug. 1991, Appendix Table 6.

[33] PBS, "The history of commercial aviation seen through the eyes of its innovators," *Chasing the Sun*, on the Internet at **http://www.pbs.org/kcet/chasingthesun/planes/747.html**.

[34] Robert J. Samuelson, "Economic Focus," *National Journal*, Sept. 19, 1981, p. 18.

[35] Airliners.net: Airbus A300-600, on the Internet at **http://www.airliners.net/info/stats.main?id=18**.

[36] Airliners.net: Boeing 757-200, on the Internet at **http://www.airliners.net/info/stats.main?id=101**; Honeywell, "Integrated Avionics Systems," on the Internet at **http://www.myflite.com/myflite/products/ias/p1000/14Electronic%20Flight%20Instruments%20Systems.jsp**.

[37] Airliners.net: Airbus A320, on the Internet at **http://www.airliners.net/info/stats.main?id=23**.

[38] Chris Wenham, "Fly by wire," Sept. 24, 2002, on the Internet at **http://www.disenchanted.com/dis/technology/fly-by-wire.html**.

[39] Boeing 777-200, Airliners.net, on the Internet at **http://www.airliners.net/info/**.

[40] Air Transport Association, "Air Transport 1996," p. 1.

[41] Air Transport Association, "The Airline Handbook-Online Version," Chapter 9, p. 1.

[42] See the Energy Information Administration's Web site on the Internet at **http://www.eia.doe.gov/cabs/chron.html**.

[43] Air Transport Association, "The Airline Handbook-Online Version," Chapter 9, p. 1.

[44] Standard & Poor's, Industry Surveys-Airlines, March 27, 2003, p. 22.

[45] Richard M. Weintraub, "U.S. Probes Delta on Bookings; Justice Eyes Pressure on Start-Up Carrier: [Final Edition]," *The Washington Post*, Oct. 9, 1993, p. A.12.

[46] Base commissions are set as a percentage of the price of a ticket.

[47] Standard & Poor's, Industry Surveys-Airlines...

[48] Tim Stevens, "GPS comes down to Earth," *Industry Week*, May 20, 1996, p. 140.

[49] Philip J. Klass, "FAA cancels MLS in favor of GPS," *Aviation Week & Space Technology*, June 13, 1994, p. 33.

[50] Anonymous, "Science and Technology: Local, global positioning," *The Economist*, Sep. 26. 1998, p. 84.

[51] Robert W. Moorman, "The big eye in the sky," *Air Transport World*, April 1999, p. 38.

[52] Kathleen Hickey, "Testing testing," *Traffic World*, Feb. 12, 2001, p. 26.

[53] Don Phillips, "White House Studies Safety at National; Bush Wants Airport Open Soon; Range of Systems Could Help Prevent Airliner Attacks:[FINAL Edition]," *The Washington Post*, Oct. 1, 2001, p. B.01.

[54] Air Transport Association, "The Airline Handbook-Online Version," Chapter 7, p. 4.

[55] Bruce D. Nordwall, "ADS-B Used For IFR Vectors," *Aviation Week & Space Technology*, Jan. 22, 2001, p. 48.

[56] James Ott, "ADS-B-Related Tests Find Louisville Home," *Aviation Week & Space Technology*, July 29, 2002, p. 55.

[57] Daniel Fisher, "Free Flight," *Forbes*, Feb. 3, 2003, p. 74.

[58] Anthony L. Velocci, Jr., " IN THE EYE OF THE STORM," *Aviation Week & Space Technology*, Feb. 29, 2004.

[59] Loren Farrar, "As good as it gets?," *Air Transport World*, December 2003, p. 52.

[60] Anthony L. Velocci, Jr., "Can Majors Shift Focus Fast Enough To Survive?," *Aviation Week & Space Technology*, Nov. 18, 2002.

[61] Edward Wong, "American Not Ruling Out a Discount-Fare Airline," *The New York Times*, Nov. 7, 2003, p. C.4.

[62] Anthony L. Velocci, Jr., op. cit.

[63] The expansion of the low-cost, low-fare airlines' and regional carriers' route systems, particularly to secondary airports, have facilitated this trend.

[64] Christopher Fotos, "Airports: Industry Gauges Airlines Setbacks," *Commercial Aviation*, Aug. 21, 2002.

APPENDIX: Indexes of multifactor productivity

Most of the data used to develop the measures in this article are maintained by the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation. The data are collected through a mandatory monthly census and are defined by 'Form 41' carriers.[1] The analysis of the airline industry is based on the passenger and cargo operations of the scheduled and unscheduled airlines in the United States. The BLS measure includes only the major and regional carriers.[2] Indexes of multifactor productivity and related series are available at **http://stats.bls.gov/mfp/home.htm**.

Output

The output of an industry generally consists of numerous products or services that must be combined or weighted together in some meaningful way. For constructing measures of multifactor productivity, the preferred output index weights the difference, between times T and T-1, in the natural logarithms of the quantities of all products or services made in the industry with each product's share in the total cost of production. The cost shares are constructed as the arithmetic average of the share at time T and T-1. The exponentials (antilogs) of the sums of the cost-share weighted changes are chained together to form the index. This measure, known as a Tornqvist index, is calculated with the following formula :

$$\Sigma_i(S_i * (\ln(Q_i)^T - \ln(Q_i)^{T-1}))$$

where i stands for individual products or services and T stands for years, and where the cost share weights S_i are calculated as:

$$S_i = 1/2 * (((C_i^{\,T} * Q_i^{\,T})/\Sigma_i(C_i^{\,T} * Q_i^{\,T})) + ((C_i^{\,T-1} * Q_i^{\,T-1})/\Sigma_i(C_i^{\,T-1} * Q_i^{\,T-1})))$$

where C is the unit cost of the product or service and Q is the quantity.

The output measure for air transportation is a Tornqvist aggregation of domestic passenger miles, international passenger miles, domestic freight ton-miles and international freight ton-miles of U.S. carriers.[3] Air couriers are classified in NAICS 4921 and are excluded from the BLS measure. Data on passenger miles and freight ton-miles are taken from the Air Carrier Traffic Statistics publication of the Office of Airline Information, Bureau of Transportation Statistics, for all Form 41 reporting carriers excluding couriers. Revenue data for the weights are taken from Air Carrier Financial Statistics of the same source.

Labor input

Average hours of employees in air transportation are not available, and a constant workweek of 40 hours is assumed. The employment index measures the change in aggregate employment over time. Although the Current Employment Statistics program of the BLS does collect employment data for air transportation, it does not match the production boundary of the output data from the BTS. Consequently, the monthly employment statistics for 'Form 41' carriers from the BTS are used. The monthly data are averaged to create an annual figure, and then indexed. Employees are treated as homogeneous and additive. Hence, changes in qualitative aspects of employment such as in the skills, education, and experience of persons constituting the aggregate, are not reflected in the labor input indexes.[4]

Capital

The capital input index is based on the flow of services derived from the stock of physical assets. For most industries, capital stocks of equipment and structures are calculated from investment data by the perpetual inventory method. For air transportation, this method is followed for assets other than airframes and engines. However, the perpetual inventory method was not used to measure capital stocks of airframes and engines.

A physical count of end-of-year inventory of airframes and engines and their purchase prices is reported annually on Form 41 (report number B-43) to the Bureau of Transportation Statistics. The availability of these data and the fact that investment data for airframes and engines are somewhat problematic led to the use of weighted physical counts of aircraft and engines by type to create capital stocks for these assets. Problems with a perpetual inventory accounting of airframes and engines include double counting of investment and premature retirement out of the U.S. carrier fleet. Double counting of investment occurs when aircraft are sold by the original buying carrier to another

U.S. carrier. In this case, the original investment remains in the capital stocks until the end of the service life of aircraft and also is added to the stock again when the second carrier buys the aircraft from the first carrier. Premature retirement out of the U.S. carrier fleet occurs when a U.S. carrier sells a plane before the end of its service life to a foreign carrier. It remains in the perpetual inventory calculated capital stock of U.S. carriers.

To compute a weighted index of airframes and engines, the end-of-year inventories for 44 types of planes and 34 types of engines were assembled from the B-43 reports for 1972 forward. All operating airframes and engines are counted whether purchased, leased, or capitalized leased. Purchase prices are also reported in the B-43 reports and are used as weights. The prices used were ones that were as close to original purchase prices as possible, renormalized to base years of 1977 and 1987 with the Producer Price Index (PPI) for aircraft and the PPI for engines. The 1972–87 segment was aggregated with 1977 weights, and the 1987 forward segment was aggregated with 1987 weights. New weights will be introduced periodically into the measure. The perpetual inventory method was used for non-aircraft capital, which includes assets such as surface transport vehicles, food service equipment, ramp equipment, and maintenance buildings.

The perpetual inventory method was used to measure stocks at the end of a year equal to a weighted sum of all past investments, where the weights are the asset's efficiency relative to a new asset. Constant-dollar capital stocks were thus calculated for the non-aircraft assets. A hyperbolic age-efficiency function was used to calculate the relative efficiency of an asset at different ages. The hyperbolic age-efficiency function can be expressed as:

$$S_t = (L-t) / (L-(B)t)$$

where:

S_t = the relative efficiency of a t-year-old asset
L = the service life of the asset
t = the age of the asset
B = the parameter of efficiency decline

The parameter of efficiency decline was assumed to be 0.5. This parameter yields a function in which assets lose efficiency slowly at first, then more rapidly later in life. The end-of-year stocks were averaged at T and T-1 to represent better the value of stocks actually in use during the year.

The value of inventories of parts and supplies is also included in capital stocks. This value was calculated by averaging, at years T and T-1, the end-of-year stocks of parts and supplies deflated by an average of the PPI for fuels and the PPI for aircraft parts and equipment.

The indexes for aircraft and engines, non-aircraft assets, and parts and supplies inventories were aggregated into an overall measure of capital input using cost shares based on estimated rental prices as weights. A perpetual inventory calculation of aircraft and engines was performed for the purpose of calculating an internal rate of return. Rental prices for non-aircraft assets and for inventories of parts and supplies were calculated as:

$$RP_i = [(P_i * R) + (P_i * D_i) - (P_i^T - P_i^{T-1})] * (1-UZ-K)/(1-U)$$

where:

RP_i = the rental price for asset i
P = the deflator for asset type i
R = the internal rate of return
D = the depreciation rate for asset type i
$P^T - P^{T-1}$ = the capital gain term for asset type i

(1-UZ-K)/(1-U) reflects the effect of taxation in which:
U = the corporate tax rate
Z = the present value of $1 of depreciation deductions
K = the effective investment tax credit rate

The rental prices were calculated in rates per constant dollar of productive capital stock. Rental prices for non-aircraft assets and parts and supplies inventories were multiplied by their constant-dollar capital stocks to obtain current-dollar capital costs, which are converted to cost shares for Tornqvist aggregation of the capital input index. The capital costs of aircraft and engines were derived by subtracting non-aircraft asset costs and parts and supplies inventory costs from total capital costs.

Intermediate purchases

The input of intermediate purchases includes the materials, fuels, electricity, and services consumed by air carriers. Detailed cost of materials data were available for 21 items for the years 1972–1986 and for 13 items for the years 1986–2001 from the Form 41 reports. Each item was matched as closely as possible to a Producer Price Index (PPI). For aircraft fuels and oils, data on gallons consumed were used. The detailed values were then deflated and the resulting constant-dollar values were Tornqvist aggregated.

Combined input index

The index of combined inputs is calculated as a Tornqvist aggregation of the input indexes of labor, capital, and intermediate purchases. The cost share weights were calculated by estimating the annual nominal dollar cost of each, summing them and dividing each input's cost by the total. The costs of aircraft rentals in the intermediate purchases data were moved into capital costs because rented aircraft are counted in the capital measure. Other rentals (for example, ticket counter space in airports) remain in the intermediate purchases input. The relative cost share weights for the three inputs are listed below for various years.

	Cost share weights		
Year	*Labor*	*Capital*	*Intermediate purchases*
1975	0.5256	0.0368	0.4376
1980	.3848	.0769	.5383
1985	.3604	.1234	.5162
1990	.3621	.1305	.5074
1995	.3596	.1502	.4903
2000	.3693	.1459	.4848

Footnotes to the appendix

[1] "Form 41" reports contain information on large certificated U.S. air carriers, defined as those that hold a certificate issued under section 401 of the Federal Aviation Act of 1958 and that generate operating revenues that exceed $1 billion.

[2] The commuter airlines do not file "Form 41," which is the source of capital data. Thus, they are excluded from the BLS measure. See the Web site **www.rspa.gov** for the definition of Form 41, which is the basis for the data set used in this article.

[3] A figure for passenger miles is computed by multiplying the number of passengers by the number of miles flown. Similarly, a figure for revenue-ton miles is computed by multiplying the number of freight and mail tons being transported by the number of miles flown.

[4] The effects of changes in workers' characteristics are not reflected in the labor input indexes. See *Labor Composition and U.S. Productivity Growth, 1948–90,* Bulletin 2426 (Bureau of Labor Statistics, December 1993). The bulletin uses data on worker heterogeneity in the examination of productivity growth in the private business and private nonfarm business sectors. However, reliable data on workers' traits are not available at the industry level, and hours must be treated as homogeneous and additive in the industry labor productivity measures.