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A Panel Study of Outsourced Maintenance Impact on Major U.S. Passenger Airlines' Profitability (1995-2019)

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The 1978 Airline Deregulation Act initiated the removal of government economic control of U.S. carriers, introduced the free market to the domestic airline industry, and brought about a decrease in airfares, as well as an increase in passenger volume and cargo traffic (Belobaba et al., 2016; Goetz & Vowles, 2009; Wensveen, 2011). The airlines, however, have struggled to find novel ways to maximize profits and cut costs so that they can survive various economic and political oscillations (Belobaba et al., 2016; Bruce et al., 2018; Graham et al., 1983). Airlines have increasingly outsourced fleet maintenance to third-party aircraft maintenance providers as an efficient means of reducing labor costs, a practice known as contract maintenance (Czepiel, 2003; McFadden & Worrells, 2012). While outsourcing maintenance tasks aims to reduce operational cost, there is no quantitative research that explores the effect of maintenance outsourcing on airline profitability. Hence it is worthwhile to examine this trend using empirical data to understand the relationship between the metrics pertaining to maintenance outsourcing and airline profitability.

In this study, the researchers utilized datasets from Air Carrier Financial Reports (known as Form 41 Financial Data) collected by the U.S. Department of Transportation, Bureau of Transportation Statistics (U.S. DOT Form 41 via BTS) and U.S. macroeconomic data published by the Federal Reserve Bank St. Louis to seek the outsourced maintenance impact on airline profitability. The researchers pose the following questions:

1. Does the percentage of maintenance expenses outsourced (Omx) have a statistically significant impact on profitability of the carriers under study?

2. Does the in-house maintenance labor expense have a statistically significant impact on profitability of these carriers?

The researchers will approach these questions in the following four econometric models: pooled ordinary least square (POLS), the time fixed effects model, the individual fixed effects model, and two-way fixed effects model; the best of four models will give answers to the questions. The remainder of the article will introduce a literature review on airline maintenance, discuss reasoning for outsourcing, and explore negative impacts from airline maintenance outsourcing, outline methodology, show results, reach conclusion, and expose limitations and point out future study.

Literature Review

Introduction to Airline Maintenance

"Maintenance is the action necessary to sustain or restore the integrity and performance of the airplane" (Hessburg, 2001, p. 246). For the airlines, the goal of maintenance is to facilitate safe, airworthy, and timely aircraft operations (Belobaba et al., 2016; Bruce et al., 2018; Hessburg, 2001; Holt, 2002). For lessees or aircraft owners, effective maintenance should maintain the current and future value of the aircraft/asset by minimizing physical deterioration throughout its life cycle (Bourjade et al., 2017; Scheinberg, 2017). Finally, it is a regulatory requirement for airlines to ensure that their aircraft remain airworthy (Holt, 2002; Scheinberg, 2017).

Airlines are mainly concerned with line maintenance and base maintenance. Line maintenance takes place in the flight line between flights to ensure the aircraft is fit for operation. Base maintenance is carried out in the hangar and consists of a range of maintenance activities that can be divided into letter checks based on hours of flights, flight cycles, and aircraft age (Department for Business, Innovation and Skills, 2016). Among these letter checks A through D, D check is the most comprehensive one; sometimes known as a heavy maintenance visit, it may require up to 50,000 man-hours to finish it (Department for Business, Innovation and Skills, 2016; McFadden & Worrells, 2012).

Outsourcing in Economics and Business

Outsourcing is not a new concept. Through the observation of pin manufacturing in Scotland, Adam Smith (1776/2007), the founding father of economics, discovered that division of labor could increase labor productivity and thus accelerate economic growth, and proposed that the exchange of goods and services makes trading parties better off. Coase (1937) illustrated that a firm must deal with transaction costs (marketing cost in the original text), including the cost of entering into and executing contracts, which is inherently more effective in production and trade exchange than an individual could have achieved. Coase (1937) also discovered that the process of vertical integration of a firm, which involves the combination of two or more stages of operations by different collaborative parties, would suppress the price mechanism and lead to a bigger profit margin. Built on the study of Smith (1776/2007), Coase (1937), and many others, Williamson (1991) founded a new subdiscipline called transaction economics by introducing the analysis of discrete structural alternatives to identify and detail key differences in economic organization. He found that advantages and disadvantages were present among the three primary forms of economic organization (market, hybrid, and hierarchical), and he observed that vertical integration was often a last resort when all the internal forms of adaption and cooperation within the same firm failed.

The major motivation for firms to outsource is to take advantages of wage and benefit savings offered by the third party, especially those located overseas (Abraham & Taylor, 1996; Goldschmidt & Schmieder, 2017; Mankiw & Swagel, 2006). Furthermore, Porter (1980) and Quinn and Hilmer (1994) identified that properly planned outsourcing activities allowed company managers to leverage skills and resources most efficiently so that they could focus on core competencies and strategically outsource other activities. By adopting outsourcing practices, the company can maximize its returns by concentrating its resources on the activities it can do best, building up the barriers of entry for potential market competitors and fully utilizing its suppliers' resources, capabilities, and capacity when insourcing is difficult or impossible. Görg and Hanley (2004) found that only the plants with substantial employees would benefit from outsourcing materials, and the service outsourcing's impact is mixed. An outsourcing strategy also offers a company great flexibility in the event of market and technology changes (Porter, 1980).

Airline Maintenance Outsourcing

Outsourcing is a trend in the airline industry (Callaci, 2020; Erickson et al., 1997). Initially, airlines were most likely to outsource ticket sales and distribution, food services, baggage handling, and aircraft interior cleaning (Rutner & Brown, 1999). Entering the new century, the established airlines have aggressively outsourced more non-core functions including maintenance, catering, cargo, ground handling, certain accounting functions, training, reservations, information technology support, frequent flyer programs, and non-airline functions such as property management (Holloway, 2008; North et al., 2019).

The U.S. Government Accountability Office (U.S. GAO) (2004) estimated that nearly half of U.S. airline maintenance had been outsourced to repair stations. By 2016, outsourced maintenance work was reported to be 47% of U.S. airlines' total maintenance spending, representing $7.3 billion in expenditures while some companies' expenditure budgeted as high as 75% of their total maintenance costs (Transport Workers Union of America, 2018a).

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Airlines outsource their maintenance activities to third parties for two main reasons: 1) to reduce overall cost of operations, and 2) to seek technical support from third party maintenance repair and overhaul (MRO) vendors (Erickson et al., 1997; Holkeri, 2020; Van Wagner, 2007). There are four levels of MRO operations associated with the proportion of airline outsourced work: fully integrated, partially outsourced, mostly outsourced, and wholly outsourced (Al-kaabi et al., 2007).

Airlines with large, diversified fleets and an extensive route structure tend to adopt the fully integrated MRO model (Al-kaabi et al., 2007). Lufthansa and Delta Air Lines are the industry leaders by not only operating large networks, but also by maintaining strong technical operation subcompanies (Lufthansa Technik AG and Delta TechOps). This allows them to satisfy not only the maintenance requirements of their own fleets, but also other alliance, competing airlines' fleets, and even military customers around the globe (Visiongain, 2018; Erickson et al., 1997; McFadden & Worrells, 2012).

The partially outsourced MRO model is suitable for airlines with a few dissimilar fleet types that can meet a large portion of their maintenance needs in-house with a minimum of outsourcing requirements (McFadden & Worrells, 2012). The low-cost carriers (LCCs) and some legacy carriers started to adopt this MRO strategy to bypass the negative impacts from their unions (Olaganathan et al., 2020).

The mostly outsourced model is suitable for the airlines that wish to outsource most maintenance tasks to MRO vendors and keep only critical activities in-house (Al-kaabi et al., 2007). Critical activities are activities that could affect daily operations directly associated with revenues. Line maintenance and light maintenance usually fall into this category (Al-kaabi et al., 2007; McFadden & Worrells, 2012).

The wholly outsourced MRO model is for startup carriers that lack the needed capital to establish an MRO facility. Virtual airlines also adopt the fully outsourced business model (McFadden & Worrells, 2012). “A virtual airline is an airline that has outsourced as many possible operational and business functions as it can, but still maintains effective control of its core business” (Flouris & Oswald, 2016, p. 91). In reality, no airline has fully outsourced maintenance, and the new entrant or startup airlines tend to outsource more maintenance due to the required large investment in facilities, parts inventories, tooling and staff (Rodrigues & Lavorato, 2016).

In theory, for the first two models, the airlines with large MRO operations enjoy significant economies of scale by maintaining large homogenous fleets (Smith, 1776/2007; Vega et al., 2016). In some cases, airlines initiate joint ventures with the original equipment manufacturers (OEMs) for special components like engines and auxiliary power units (APUs) (Scheinberg, 2017). Major U.S. airlines are shifting towards the latter two models, as such maintenance activities require investment in specialized training, costly equipment, and highly skilled professionals (Czepiel, 2003). This trend was especially evident between 2016 and 2019, and was driven by the diversification of fleets and strategic change of divesting non-core divisions including repair facilities (Callaci, 2020; Porter, 2008; Quinlan et al., 2013).

MRO Vendors

Third-party MRO vendors typically perform the maintenance work at a lower cost than that of airline in-house maintenance departments. It makes sense for MRO providers to work on multiple carriers’ similar aircraft and components at the same time they perform maintenance on their own fleets in order to experience greater economies of scale (Bazargan, 2016; Bazargan & Hartman, 2012; Smith, 1776/2007). Remarkably, depending on location, third-party MRO vendors may also enjoy cheaper labor rates and currency exchange rates by performing heavy maintenance in developing countries (Czepiel, 2003; Mankiw & Swagel, 2006; Quinlan et al., 2013). For instance, U.S. airlines have outsourced heavy maintenance to developing countries such as China and El Salvador to reduce costs by taking advantage of comparatively lower wages and reduced facility investments required in these countries (Tang, 2018; Zwerdling, 2009).

In addition to cost-saving capabilities, MRO vendors also possess substantial technical specialties to attract airline customers. Most outsourced maintenance concentrates on depot maintenance including heavy maintenance visits often involving structural repair and modification, corrosion control and treatment, and component maintenance activities on the communication and navigation equipment, landing gear, APU, and other myriad miscellaneous subsystems. This requires significant specialized talent and expensive equipment (Erickson et al., 1997; Holcomb & Hitt, 2006; Quinlan et al., 2013). Similarly, engine manufacturers developed Power by the Hour (PBH), an engine maintenance-outsourcing concept in which a contract maintenance company (such as an affiliate of the manufacturer) provides an airline/operator with heavy engine maintenance (Scheinberg, 2017).

Negative Impacts from Airline Maintenance Outsourcing

In the microeconomic sense, airlines and passengers may experience, or have experienced, losses by choosing to outsource maintenance practices or flying on jets whose maintenance work was outsourced (Kahneman, 2011; Smith, 1776/2007). The biggest concern is the jeopardy of aviation safety stemming from the practice of outsourced maintenance. Using an exhaustive literature review, Quinlan et al. (2013) finds that outsourcing could generate risks in four categories: economic/financial pressures, disorganization, regulatory failure, and spill-over effects.

Contract maintenance providers compete with each other on the basis of cost-reduction and time efficiency, which may lead them to implement unsafe practices that could impose threats to the quality and safety of maintenance work (Bağan & Gerede, 2019; Quinlan et al., 2013). The Federal Aviation Administration (FAA) has found in some instances that repair stations were lacking in qualified A&P mechanics and that a large number of temporary workers were employed to reduce costs and meet surges in demand (Czepiel, 2003). The disorganization of MRO vendors arises from the fact that repair stations are working on a high volume of aircraft simultaneously, so required parts are often unavailable. As a result, engineers often succumb to quick but risky solutions such as "parts robbing" or the use of suspected unapproved parts (SUPs) (Czepiel, 2003; Kinnison & Siddiqui, 2012; Olaganathan et al., 2020). The heavy workload adds extra complexity and difficulty to the maintenance planning process (Albakkoush et al., 2020; Quinlan et al., 2013; Tang & Elias, 2012). There may also be regulatory failures in monitoring ongoing revision changes at repair stations. Foreign repair stations that perform maintenance for their partners of U.S.-based airlines often do not have sufficient oversight from the FAA (Czepiel, 2003). Finally, the spillover effects are seemingly unrelated events that may have particularly negative impacts on the maintenance work quality (Quinlan, 2012; Quinlan et al., 2013). MRO vendor mechanics are often victims of poor ergonomic and biomechanical working conditions concentrating on prolonged awkward postures during maintenance and inspection, lifting heavy parts (>40lbs), and standing on the ladder while working on the aircraft (Asadi et al., 2019). In return, this can affect aviation safety as the aircraft maintenance labor force is a key part of a tightly coupled socio-technical system; the failure to protect the mechanics could contribute to an accident (Perrow, 2011; Reason, 1997, 2016; Wiegmann & Shappell, 2003). While U.S. Part 121 air carriers have excellent safety records over the past few decades (Belobaba et al., 2016; Van Wagner, 2007), poor performance in terms of on-time departure and arrival statistics may be partly explained by substandard maintenance work performed both in-house and by third parties and may suggest a future impact to aviation safety (Bağan & Gerede, 2019; CBS News Chicago, 2019; Rhoades, et al., 2005). In short, the quality of outsourced work is more dependent on the MRO providers and less dependent on the airlines. And the gravest consequence for the poor outsourced work is unsafe aviation events.

Several prominent aircraft accidents over the preceding three decades can be partly traced to outsourced maintenance: ValuJet Flight 597, ValuJet Flight 558, ValuJet Flight 592, Emery Airlines Flight 17, and Air Midwest 5481 (Quinlan et al., 2013). Among these, the deadliest air crash (110 victims) was the May 1996 ValuJet Flight 592 accident in Florida that was caused by ground staff of a third-party maintenance company loading a mislabeled box of oxygen generators in the cargo compartment of the airplane. This was a clear violation of hazardous materials (HAZMAT) shipping procedures and rules instead of maintenance error (Hessburg, 2001; National Transportation Safety Board [NTSB], 1996).

Statistically, however, there is insufficient evidence showing that outsourced maintenance has eroded major airline safety (International Civil Aviation Organization [ICAO], 2018; Tang & Elias, 2012). Geibel et al. (2008) found only 7% of errors related to contract maintenance based on 680 Aviation Safety Reporting System (ASRS) reports involving maintenance issues and human errors dated August 2004 – July 2006. Since 1976, the National Aeronautics and Space Administration (NASA) has maintained the ASRS database tracking these reports (Eisenbraun, 1980; Hooey, 2018). Such studies may generate biased conclusions because the data is not a random sample and the ASRS may receive significant reports from contributors seeking immunity from FAA violations (Eisenbraun, 1980; Lincoln & Guba, 1985; Lohr, 2010; Merriam & Tisdell, 2016). Monaghan (2011) found there is no significant correlation between the expenditure of passenger airlines' outsourced aircraft maintenance and the number of accidents and incidents per miles flown between 1996 and 2008.

For labor welfare, outsourcing practices have affected airline and MRO vendor employees in various aspects. For the airline workers, the heavily outsourced projects in the airline industry have resulted in lower wages, according to a recent study using data from 1990 through 2018 (Callaci, 2020). Earlier studies found the practice of outsourced maintenance after the Deregulation Act has downgraded working conditions by reducing investment in hangars, and the consequences included wage reductions for both airline employees and contractors and higher chances of work injury (Asadi et al., 2019; Heinrich, 1941; Johnson & Anderson, 2004; Office of Inspector General, 2008).

Airline Profitability and Maintenance

Previous research found several factors that could influence airline profitability. Parast and Fini (2010) used a stepwise regression to explore the effects of productivity and quality on profitability in the U.S. airline industry based on longitudinal data from 1989 to 2008, and they found that fuel prices and average annual maintenance cost have a negative correlation with profitability. Bazargan (2016) found that airlines with large amounts of outsourced maintenance might have less control of aircraft maintenance activities, which could result in lower utilization hours, affecting profitability. A study based on airlines in Brazil suggested that the fleet size of the airline has a negative relationship with the unitary cost of maintenance; the largest companies have lower unitary maintenance costs because they have bigger market share and enjoy the scale of economy such as planning and using resources more efficiently, while the smaller airlines have to deal with higher unit costs of maintenance and they gain cost saving and profitability through maintenance outsourcing (Vega et al., 2016).

Methodology

As the literature review indicates, airlines outsource maintenance to save money and satisfy operational needs depending on their sizes; however, outsourcing decisions come with multiple risks that may affect aviation safety and the financial and economic wellbeing of stakeholders. Hence, the researchers decided to include the following independent variables into our models: Percent of Maintenance Expenses Outsourced (Omx), Inflation Adjusted Average Annual Wages and Salaries - Inhouse Maintenance Personnel (MxWage2), Total Operating Fleet Count (TOF), and Total In-House Maintenance Employee Equivalents (MxCount). Omx indicates the degree of maintenance outsourcing; MxWage2 reflects the internal airline maintenance cost; TOF controls for the airline sizes; and MxCount controls for the airline internal maintenance scale. It should be noted that these models are descriptive in nature instead of being based on any single theoretical framework. This study intends to show what variables impact on airline profitability.

Data Sample

The researchers have retrieved a majority of the source data from U.S. DOT Form 41 via BTS data collected from the major airlines in the U.S. between 1995 and 2019, and prepared by Massachusetts Institute of Technology Airline Data Project (MIT ADP) (Massachusetts Institute of Technology, 2020). The data of inflation rate were retrieved from the Federal Reserve Bank St. Louis (Economic Research Federal Reserve Bank of St. Louis, 2020).

There are 200 data points from eight major airlines as seen in Appendix A; however, some data are missing: Omx has seven missing data points, and MxWage has three. These comprise less than 5% of total data, so the missing data problem was resolved by imputing of the mean values (Jakobsen, et al., 2017). Hence, the sample size for this study is 200 (n = 200).

Models

Panel data is a popular and interesting way to research economic problems due to its ability to capture the effects on relationships between dependent variables and independent variables (Park, 2011; Wooldridge, 2013).

Using static panel data modeling for eight airlines from 1995 and 2019, the researchers estimated the effects on the real profitability of each airline (Profitability2) from the following independent variables: Omx, MxWage2, MxCount, and TOF. A detailed explanation of the dependent variable, the independent variables, and other correlated variables is presented in Table 1.

Table 1

Variables in the Study

Variable	Explanation
Year	Year ranging from 1995 to 2019.
Airline	Airline Names.
Revenue	System Total Operating Revenue count in billion U.S. dollar.
Expense	System Total Operating Expense count in billion U.S. dollar.
Profitability	It comes from formula: (Revenue-Expense)/Expense.
InflationRate	Consumer Price Index for All Urban Consumers: All Items in U.S. City Average, Compounded Annual Rate of Change, Annual, Seasonally Adjusted.
Profitability2	Real profitability: Profitability minus InflationRate.
Omx	Percent of Maintenance Expenses Outsourced.
MxWage	Average Annual Wages and Salaries - INHOUSE MAINTENANCE PERSONNEL.
MxWage2	MxWage adjusted for inflation.
MxCount	Total In-House Maintenance Employee Equivalents.
TOF	Total Operating Fleet. It is equal to Aircraft Days Assigned/Days in Year. Represents average fleet count over the course of the entire year.

The dependent variable in this study is Profitability2, the independent variables of interest are Omx and MxWage2, and the rest of the control independent variable: TOF are included to controls for the airline sizes. Together, they form the following model in Equation 1, in which β_0 is the intercept, β_1 to β_3 are the coefficients of the independent variables described in the table above, and ε is the error term.

$$Profitability2 = \beta_0 + \beta_1 * \ln(Omx_{it}) + \beta_2 * \ln(MxWage2_{it}) + \beta_3 * \ln(MxCount_{it}) + \beta_4 * \ln(TOF_{it}) + \varepsilon \quad (1)$$

The researchers began with a Pooled Ordinary Least Square (POLS) model. The POLS model is built on the assumption that the error terms are independent and identically distributed; the model treats all the data as a set of cross section observations, and can be mathematically expressed as:

$$y_{it} = \alpha + X'_{it} * \beta + v_{it} \quad (2)$$

The POLS model of Equation 2 consists of y_{it} denoting Profitability2, α constant as known as intercept, X'_{it} independent variables being expressed in the matrix form, β the coefficients of the independent variables in parameter vector, and v_{it} denoting error term specific to time and individual effect.

In addition to the POLS model, there are four advanced models: three fixed effects models and one random effects model. They are a time fixed effects model, an individual fixed effects model, a two-way fixed effects model, and a random effects model. Their mathematical expressions are listed below, respectively.

$$y_{it} = (\alpha + u_t) + X'_{it} * \beta + v_{it} \quad (3)$$

$$y_{it} = (\alpha + u_i) + X'_{it} * \beta + v_{it} \quad (4)$$

$$y_{it} = (\alpha + u_t + u_i) + X'_{it} * \beta + v_{it} \tag{5}$$

In all the models expressed in Equations 3 to 5, α is the constant term across four models, $X_{it}^{'}$ independent variables being expressed in the matrix form, β the coefficients of the independent variables in parameter vector, and v_{it} denoting error term specific to time and individual effect. The fixed effects models estimate u_t as time differences in intercept in Equation 3, u_i as individual differences in intercept in Equation 4, and u_t and u_i as both time and individual differences in intercepts in Equation 5, assuming the same slopes and constant variance across individual (group and entity) variables and/or time.

Once all the model results were calculated, the researchers applied a series of tests to the models listed above to determine the best model. A Chow F test was used to test the joint significance of the included fixed effects parameters, and the failure to reject the null hypothesis indicates the POLS model has the most efficient estimator; Otherwise, fixed effects models (time fixed, individual, or two way) are favored over the POLS model (Chow, 1960; Wooldridge, 2013). Reed and Ye (2009) suggested that the econometrician choose, as the most efficient model, the one with the lowest root mean square error. The researchers used this approach to determine the best fixed model. The root mean square error (RMSE) is expressed in Equation 6.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{\widehat{y_i} - y_i}{n}} \tag{6}$$

In this equation, $\widehat{y_i}$ is the predicted value of Profitability2 of each model, and y_i is the actual value of Profitability2 of the data, n is the sample size of each model.

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Results

The descriptive statistics of the variables and the results for the best model are presented in the following tables. Table 2 shows the descriptive statistics of the dependent variables and the independent variables, and Table 3 shows the correlation matrix.

Table 2

Descriptive Statistics

	Profitability2	Omx	MxWage2	MxCount	TOF
Mean	0.043	0.47	82953.34	4080.122	329.167
SD	0.1020063	0.209	94813.57	5105.394	295.127
Min	-0.217	0.001	24183.23	13	5.362
Max	0.315	1.375	755139.7	18187	971.89

Table 3

Correlation Matrix

	log(Omx)	log(MxWage2)	log(MxCount)	log(TOF)
log(Omx)	1			
log(MxWage2)	0.033	1		
log(MxCount)	0.092	0.651	1	
log(TOF)	-0.010	-0.622	-0.933	1

The correlation matrix of the independent variables and variance inflation factors (VIF) are calculated for all independent variables for testing multicollinearity. VIF ranges from 1.056

to 8.669. Using a commonly applied rule of 10 (for VIF), this suggests that the independent variables of the current study are not multicollinear.

The results of the best models are presented in Table 4, and the other model results are presented in Appendix B.

Table 4

Results of the Individual Fixed Effects Model

	Estimate	SE	t-value	Pr(>|t|)	
log(Omx)	0.015	0.010	1.576	0.117	
log(MxWage2)	0.010	0.018	0.574	0.567	
log(MxCount)	0.006	0.013	0.473	0.637	
log(TOF)	0.084	0.022	3.815	0.000	***
TSS	1.863				
RSS	1.549				
R-Squared	0.168				
Adj. R-Squared	0.120				
F-statistic	9.253 on 4 and 188 DF				
p-value	0.000				

Note. SE stands for standard error, TSS stands for total sum of squares, RSS stands for residual sum of squares. Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1.

The individual fixed effects model is considered the best model based on the results of p-value of each model, the Chow test for fixed effects models against POLS model, and the RMSE test. The detailed selection process is presented in Appendix B.

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Conclusion

In summary, the researchers used four models: POLS, a time fixed effects model, an individual fixed effects model, and a two-way fixed effects model to explore whether there are correlations between the amount of maintenance outsourced and airline profitability and between the airline maintenance labor cost and airline profitability based on empirical data from U.S. DOT Form 41 via BTS and the Federal Reserve Bank. The results show that there are no statistically significant correlations. The researchers offer one possible explanation for the results, and that is that the scale of maintenance outsourcing has effectively reduced the cost of the maintenance via the reduction of in-house maintenance activities and maintenance labor and has consequently lowered its percentage of total operating costs while other costs have increased (Czepiel, 2003; U.S. GAO, 2004; IATA's Maintenance Cost Technical Group, 2019; Office of Inspector General, 2008; Transport Workers Union of America, 2018b).

Limitations and Future Study

An econometric study has the following limitations: omitted variable bias, error-in-variables bias, and sample selection bias as identified by Stock and Watson (2003). One key variable omitted is the age of commercial aircraft, which is highly correlated with maintenance cost and potentially profitability of airlines (Dixon, 2005). This omission is due to data unavailability. In previous research, the researchers have used other independent variables such as fuel prices and maintenance cost, which may affect the independent variables that correlate with airline profitability (Parast & Fini, 2010). Also, a small number of data were not collected, and subsequent values were imputed (Jakobsen et al., 2017) Airline profitability as utilized herein is reported annually and may not truthfully reflect long-term airline financial performance (Noronha & Singal, 2004). The carriers studied were viable major U.S. passenger airlines;

previously existing bankrupt counterparts were omitted for ease of calculation (Wooldridge, 2013). In 2020, the pandemic also affected all the selected variables in the study and may suggest the need for an updated study (Sobieralski, 2020).

Future studies can be improved by using more data and more comprehensive sample selection by enlarging the sampled airlines (the future study may add major cargo carriers and regional carriers) and selecting more time periods to explore the correlation between the independent variables of interest related to outsourced maintenance and dependent variables of airline financial performance.

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Appendix A

Major Airlines Included in this Study

American Airlines

Delta Air Lines

United Airlines

Southwest Airlines

Frontier Airlines

Alaska Airlines

Hawaiian Airlines

Spirit Airlines

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Appendix B

Table B1

Results of the POLS Model

	Estimate	SE	t-value	Pr(>|t|)	
(Intercept)	-0.224	0.210	-1.066	0.288	
log(Omx)	0.019	0.009	2.056	0.041	*
log(MxWage2)	0.023	0.018	1.295	0.197	
log(MxCount)	-0.017	0.011	-1.544	0.124	
log(TOF)	0.029	0.014	2.065	0.040	*
TSS	2.07				
RSS	1.887				
R-Squared	0.089				
Adj. R-Squared	0.07				
F-statistic	4.759 on 4 and 195 DF				
p-value	0.001				

Note. SE stands for standard error, TSS stands for total sum of squares, RSS stands for residual sum of squares. Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1.

Table B2

Results of the Time Fixed Effects Model

	Estimate	SE	t-value	Pr(>|t|)	
log(Omx)	0.012	0.007	1.833	0.068	.
log(MxWage2)	-0.013	0.014	-0.896	0.372	
log(MxCount)	-0.021	0.008	-2.502	0.013	*
log(TOF)	0.026	0.010	2.506	0.013	*
TSS	0.846				
RSS	0.790				
R-Squared	0.065				
Adj. R-Squared	-0.088				
F-statistic	2.993 on 4 and 171 DF				
p-value	0.020				

Note. SE stands for standard error, TSS stands for total sum of squares, RSS stands for residual sum of squares. Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1.

Table B3

Results of the Two-Way Fixed Effects Model

	Estimate	SE	t-value	Pr(>|t|)
log(Omx)	0.002	0.007	0.262	0.794
log(MxWage2)	-0.003	0.013	-0.260	0.795
log(MxCount)	0.013	0.010	1.342	0.181
log(TOF)	0.018	0.019	0.904	0.367
TSS	0.638			
RSS	0.614			
R-Squared	0.037			
Adj. R-Squared	-0.168			
F-statistic	1.589 on 4 and 164 DF			
p-value	0.180			

Note. SE stands for standard error, TSS stands for total sum of squares, RSS stands for residual sum of squares. Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1.

It may be noted that all the models except the two-way fixed effects model have statistically significant results, and it is necessary to use the techniques described previously to determine the best model. First, the researchers used the Chow test to determine whether the fixed effects models are better than the POLS model (Chow, 1960). The Chow F test results are shown in Table B4 using the R plm package (Croissant & Millo, 2008).

Table B4

Results of the Chow Tests

	F test for time fixed effects model	F test for individual fixed effects model
F	9.882	5.854
df1	24	7
df2	171	188
p-value	0.000	0.000

Based on these results, the researchers favored both fixed effects models over the POLS model. Furthermore, more are tests needed to distinguish the best fixed effects model. The RMSEs of all the fixed effects models are calculated and presented in Table B5.

Table B5

RMSE of the Fixed Effects Models

	Time fixed effects model	Individual fixed effects model
RMSE	0.109	0.103

Between two fixed effects models, the individual fixed effects model has the lowest RMSE, and it is the ultimate model to explain the data.

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