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The Impact of Civil Aviation Growth on CO_2 Emissions in India: Evidence from a Time Series Analysis

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THE IMPACT OF CIVIL AVIATION GROWTH ON CO_2 EMISSIONS IN INDIA: EVIDENCE FROM A TIME SERIES ANALYSIS

Priyanka Saharia∗ and Krishna Raj∗∗

Abstract

The Indian civil aviation industry is one of the fastest growing service sectors in India. Considering the growing importance and demand for air travel, this study investigates the effects of revenue passenger kilometer (RPK) of the airline industry, wholesale price index (WPI) of aviation turbine fuel (ATF), fuel efficiency of aviation turbine fuel and per capita income of the country on CO_2 emissions from aviation turbine fuel by using yearly time series data for the period 1988 to 2017. To find out the long run relationship between RPK, WPI of ATF, fuel efficiency, GDP-per capita and CO_2 emissions, the study uses the ***Autoregressive Distributed Lag model (ARDL)*** *with the* ***Bound test*** *approach.* ***Bound test*** *approach is applied to estimate if there is a long run relationship among the variables. The empirical results suggest that there exists a long run relationship between CO_2 emissions, revenue passenger kilometer, fuel efficiency and per capita income of the country. This study used* ***the error correction term*** *of the* ***ARDL*** *model to find the short run relationships between these variables.* ***Toda-Yamamoto*** *causality test is performed to check the causality among the variables. Empirical estimation of the ARDL model shows that both in the short run and long run, except the variable wholesale price index of ATF, all other variables are significant in relation to CO_2 emissions from ATF. Empirical results of the* ***Toda-Yamamoto*** *test suggest a unidirectional Granger causality running from revenue passenger kilometer (RPK) and wholesale price index of aviation turbine fuel to CO_2 emissions. The result also shows that there is a bi-directional causality existing between per capita income and fuel efficiency to the CO_2 emissions from aviation turbine fuel. The study also suggests that more focus on increasing the efficiency of fuel will lead to a sustainable growth of the industry.*

Introduction

Air transportation is an indispensable component of modern society and plays an integral role in the development of the economy. The rapid growth of aviation provides economic benefit and greater mobility for the world's population. Aviation contributes to 1.5 per cent of India's GDP and supports 9 million jobs, and the country ranks 9^{th} in the global civil aviation market. In the world of globalization, the growth of air traffic is much greater than the economic growth, as this has been proved in economic theories and analytical studies. These studies have found that there is a high correlation between world economic growth and air transport growth (François Bourguignon, 2016). The phenomenal growth of the sector has inevitably also led to environmental challenges. Aviation is increasingly being classified as a major source of Green House Gas (GHG) emissions, a significant contributor to global climate change and source of air pollutants. According to the Paris Agreement on climate change, aviation is one of the fastest growing sources of GHG emissions and the most climate intensive form of transport. It's CO_2 and non CO_2 impacts are responsible for some 4.9% of manmade global warming (Aviation Emissions and the Paris Agreement, 2016). The world's 16,000 commercial jet aircraft per year generate the world's major GHG which is more than 600 million tones of CO_2. Indeed, aviation generates nearly as much CO_2 annually as that from all human activities in Africa (Yenneti Komalirani, 2010). Further, different types of aircraft emissions can affect the climate in numerous ways like emitting CO_2 and water to do so

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directly and other effects like production of ozone in the troposphere, lifetime alteration of methane, formation of contrails etc. As an alternative fuel use, hydrogen fuel reduces the emissions of CO_2 but increases the content of water vapor, so the overall environmental impact will not be reduced (Jardine, 2009). Hence, immediate action is required to address the environmental impact of the industry. Therefore, improvement in air traffic management and other operational procedures can effectively reduce the CO_2 emissions, varying from 8% to 18%, which will depend on institutional management (Aviation Emissions, Impacts & Mitigation: A primer , 2015).

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) has requested the International Civil Aviation Organization (ICAO) to work on the reduction of emissions from the air transportation sector. Tracking emissions from international aviation is not included in national inventories. Apart from the above, ICAO and other parties have delayed work on the reduction of emissions from aviation by two decades and meanwhile, emissions from international aviation grew by over 75% during the period 1990 to 2012. Compared to the emissions growth rate of all sectors of the economy, the growth rate of emissions from civil aviation is more than twofold (Aviation Emissions and the Paris Agreement, 2016).

As a result, in the year 2015, the UN climate change conference in Paris proposed to freeze carbon emissions by the aviation industry at 2020 levels. This deal will be voluntary between 2021 and 2026. It will be mandatory from 2027 for the world's largest emitters including emerging aviation powers such as India, China and Brazil (Why is India opposing UN proposal on aviation emission?, 2016). Given the above agreement and target, the growing negative environmental impacts of the civil aviation industry can create fundamental constraints on the growth of the industry in the 21st century.

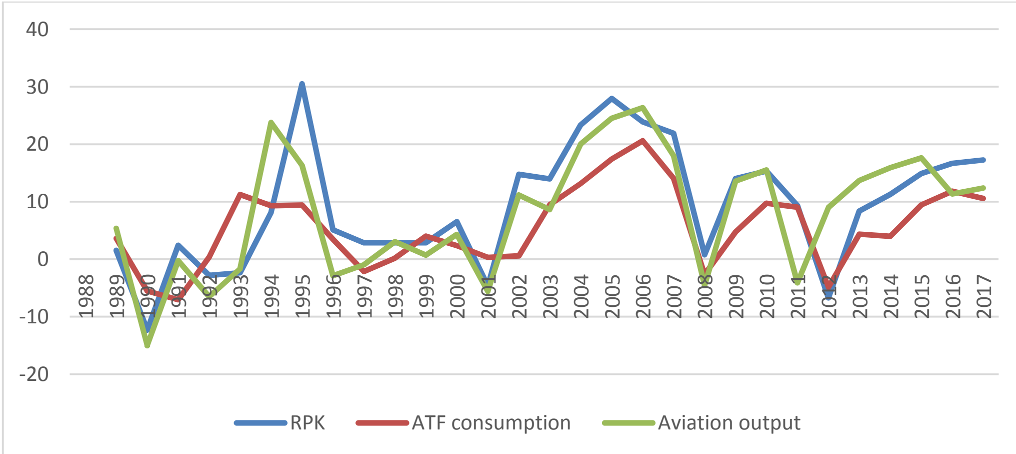
Being the third largest Green House Gas emitter, India has expressed its disagreement with the proposal of the Paris climate change agreement to follow the aviation cap, fearing a slowdown in the Indian aviation sector which is already surviving on thin profit margins; and the government has categorically refused to agree to the move. In a country like India, the ICAO proposal will not only impose an inappropriate economic burden on the emerging sector, but also deprive its people from accessing it. Further, the rising fuel prices are making Indian carriers more vulnerable to international competition and they are scrambling to reduce non-fuel cost to improve the bottom-line.

Hence, this study attempts to analyze the relationship between fuel price, fuel consumption, CO_2 emissions and civil aviation growth in India.

Air Traffic Growth in India

The contribution of aviation was the second highest after road transportation. This has been reflected in air traffic growth and CO_2 emissions. The growth of air traffic is shown in the following graph. A government Green House Gasemissions inventory for India shows that all the modes of transportation put together contributed 8.2% to the total national CO_2 emissions in 2007.

Figure 1: Trend in Growth Rates of Aviation Output, ATF Consumption and Air Traffic



Source: Authors' calculation using MOSPI GOI, DGCA GOI, for various years

The above graph shows the trend of air traffic growth in terms of revenue passenger kilometer, growth rate of ATF consumption and growth rate of aviation output for the period 1988 to 2017. Data of aviation output and ATF consumption is collected from energy statistics, MOSPI and Revenue Passenger Kilometer are collected from the Director General of Civil Aviation. X-axis of the graph represents the time span of the study i.e 1988 to 2017 and Y-axis of the graph represents revenue passenger kilometer, output of air transport and consumption of aviation turbine fuel in India. In the graph, we see there is a strong positive relation between the growth rate of output of air transportation, ATF consumption and air traffic. Studies have found that the demand for air travel is primarily determined by economic development, and hence there is a strong positive correlation between air traffic growth and economic growth. The International Energy Agency (IEA) has calculated 14.34 Mt CO_2 emissions from international aviation to and from India in the year 2007 and an exceptional increment of 165.7% between 1990 and 2008, compared to the world average of 76.1%. Environmental issues regarding emissions from aircraft were originally related to their contribution to local air quality within the vicinity of the airport.

Statistical analysis has shown that growth in GDP now explains about two-third of air travel growth reflecting increasing commercial and business activity and increasing personal income and propensity to travel. Again, increased air traffic requires more number of carriers, which eventually leads to more consumption of ATF.

Literature Review

Many studies have established a direct relationship between the growth of the aviation industry and CO_2 emissions. However, the recent improvement in technology has helped in reducing the emissions level by the civil aviation industry. The special report of the Intergovernmental Panel on Climate Change (IPCC) on the aviation industry shows that there is 70% reduction in the emissions in the past 40 years due to the efficient contribution of backstop technology to improvements in manufacturing aircraft. However, contrary to the above improvements in technology, several studies have shown that fuel consumption of aviation is the main concern and they suggested reduction of fuel consumption by 80-90% for making the sector a sustainable one. But it is not feasible to achieve the target with the given technology of aircraft flying by high crude speeds and altitude (Stefan Gossling *et al*, 2007).

A report prepared for ICAO by the IPCC in 1999 found that CO_2 emissions could rise between the range of 60 to 1000 per cent during the period of 1992 to 2050 (Vedantham, 1999).

To have a better understanding about carbon emissions associated with commercial aviation, we have reviewed a few available empirical studies as follows:

Olsthoorn *et al* (2001) studies the CO_2 emissions from international aviation for a time series analysis of 29 years to figure out the significant relationship between the sales of bunker jet fuel, world crude oil prices and global gross domestic product. The econometric model adopted in the study allows for the forecasting of future emissions. It forecasts that between 1995 and 2050, emissions of CO_2 may increase by a factor varying from 3 to 6.

Another study finds that international aviation carbon di-oxide will increase by more than 110 per cent between 2005 and 2025 and that it is unlikely emissions could be stabilized at levels consistent with risk adverse climate targets without restricting demand (Andrew Macintosh, 2008).

V Andreoni(2012) conducted a decomposition analysis to analyze the factors influencing European CO_2 emissions variation of water and aviation transport activities for the period 2001-2008 for 15 European countries. Findings of the study indicate that economic growth is the main factor for the increased CO_2 emissions for both water and aviation. In the aviation sector, it was found that reduction in energy efficiency has been the main driver of emissions increase.

Lonza (2016) analyzed the future growth of aviation, the resulting fuel demand and deployment of bio fuels in the European aviation sector. Aviation growth and the resulting fuel demand have been projected on a year-to-year basis up to 2030, using 2020 as the baseline. The relevant variables for the study are the number of flights, types of aircraft, passenger and cargo tonnes, RPK, fuel consumption and CO_2 emissions. Empirical results of CO_2 emissions projection up to 2030 show a steady annual increase in the order of 3%, 1 % and 4% on average. The study also provides that a steady increase of CO_2 emissions has a good correlation with annual traffic growth rates.

Brandon Graver (2019) develops a bottom up approach to estimate the global aviation CO_2 inventory for the calendar year 2018. The total global carbon emissions and operations are estimated in this study in terms of revenue passenger kilometer and freight tonne kilometer with aggregate industry estimates. A total of 39 million flights from 2018 were analyzed and it was found that total CO_2 emissions from all commercial operations totalled 918 million metric tonnes in 2018, accounting for 2.4 percent of global CO_2 emissions. Data shows that passenger transport accounted for 81 percent of total emissions from commercial aviation in 2018. The findings of the study show that CO_2 emissions from aviation are distributed unequally across nations. The top countries for passenger aviation related carbon emissions were China, UK, Japan and Germany, whereas less developed nations containing half of the world's population accounted for only 10 per cent of all emissions.

Studies have also focused on the environmental cost associated with the airline market and passengers' willingness to compensate for the environmental damage caused by their air travel. Schipper (2004) estimated environmental costs in a set of 36 European airline markets. The results of the study suggest that the environmental cost represents only 2.5 % of the internal cost of aviation as measured by the average ticket price. Noise costs are found to be the dominant cost at some 75% of the total cost.

R Brouwer (2008) conducted a survey of air travel passengers at Amsterdam Schiphol airport to investigate if there is a demand for climate change mitigation. The study was meant to reveal whether air travel passengers as polluters are supportive of measures that increase the cost of their travel and compensate the damage caused by their flights through willingness to pay (WTP) measurement. Findings of the study show that 75 % of the passengers are willing to pay on average € 25 per t CO_2-eq emitted. On the supply side, the average price per capita t CO_2-eq is currently around € 12. Hence the study concludes that the market potential for carbon offset is substantial.

In India, prior to economic liberalization, civil aviation was an infant industry that was responsible for a small proportion of the transportation task and CO_2 emission. Today, it is an integral part of the transportation industry, with a double digit growth rate in domestic air passenger traffic having a significant impact on CO_2 emissions.

A study done in India considering the Delhi-Mumbai route concentrates on ways that we can reduce CO_2 emissions from aviation. Yenneti Komalirani (2010) studies ways in which benefits of GHG reduction can be captured through improvement in operations along with identifying sustainable long run solutions for airlines. The study was undertaken on the Delhi-Mumbai route for their analysis. According to an official airline guide, Delhi-Mumbai in India is contributing to 50 per cent of the total Indian air traffic, and the study estimates that the average fuel wastage per flight in the Delhi-Mumbai route is around 30-40 percent. Aviation fuel produces about 2.15 kgs of CO_2 emissions per litre. In terms of CO_2 emissions, 115,000 extra litres of fuel burnt everyday due to poor traffic and congestion management lead to 248.2 tonnes of CO_2 emissions. It is also observed by the study that there is a significant potential for emissions reduction, fuel savings and further cost savings by implementing operational strategies like air traffic management, a continuous descent approach and optimizing routes. Air traffic management can save fuel worth 10 million dollars, the continuous descent approach can save fuel worth of 8 million dollars and optimizing routes can save fuel worth 1844 million dollars for the Delhi-Mumbai route.

According to the report of the carbon footprint of aviation industry, 2013 by the Government of India, the total amount of carbon emitted by the Indian scheduled passenger airline operations to and from domestic destinations is 6,365,000 tonnes, whereas CO_2 emissions from both Indian and foreign airlines to international destinations from India are estimated at 6,472,000 tonnes. The CO_2 emissions for foreign scheduled airlines to international destinations from India have increased by 1.57 % compared to 2011 and reduced by 3.91% compared to 2012 in 2013. If there is no measure taken to control the carbon emissions by the aviation industry, it will reach 30 million by 2020. For the long term evolution of CO_2 emissions , the Ministry of Petroleum and Natural Gas forecasts an annual growth rate of aviation turbine fuel consumption of 8 per cent for the period of 2017-2020 and for 2021-2050 it is expected to be 7 per cent (Carbon Footprint of Indian Aviation, 2013).

From the above literature, we can conclude that CO_2 emissions and aviation growth have always been a matter of concern associated with its environmental sustainability. Studies have predicted the emissions from aviation in future and their contribution to current CO_2 emissions associated with other variables. There are several studies mentioning the economics of aviation emissions in the global context. In India, the Ministry of Civil Aviation under the Government of India has brought out a white paper on the National Green Aviation Policy on 19th February, 2019, expressing the sustainability and environmental concerns of the civil aviation industry. The Directorate General of Civil Aviation publishes an annual report on the carbon footprint of the aviation industry. But academic research related to the economics of aviation emissions in India is very limited. This study attempts to bridge the gap by estimating the relationship between CO_2 emissions, fuel consumption, fuel price and aviation growth for the Indian air transportation industry.

Data and Methodology

The study is based on secondary data collected from different sources. The time period of the study is from 1988 to 2017. The main variables selected for the estimation are Revenue Passenger Kilometer, consumption of Aviation Turbine Fuel, CO_2 emissions from aviation turbine fuel, GDP per capita and Wholesale Price Index of Aviation Turbine Fuel (ATF). Data on all the selected variables are collected at constant prices of different years and they are converted to one common base year of 2004-05. This study follows the ARDL approach for verifying and estimation of the impact of selected variables. Further, this study finds out the co integration of variables for the short run and long run relationship.

Table 1: Data sources and variable selection

Sl No	Variables	Units	Sources of Data
1	Revenue passenger kilometer	Million	Director General of Civil Aviation
2	Aviation turbine fuel consumption	Million tonnes	Energy statistics, MOSPI
3	CO_2 emissions	tonnes	Authors' calculation
4	GDP per capita	Rs in crores	National account statistics, MOSPI
5	Wholesale price index of aviation turbine fuel	-------	Energy statistics, MOSPI
6	Efficiency of aviation turbine fuel		Authors' calculation

The main objective of the paper is to study the relationship between fuel price, fuel consumption, aviation growth and CO_2 emissions in India for the period 1988 to 2017. The rationale behind the selection of variables is as follows:

Fuel consumption: Fuel efficiency and CO_2 emissions are being calculated using data of consumption of ATF. Data on the consumption of aviation turbine fuel in million tonnes is collected from energy statistics, Ministry of Statistics and Programme Implementation (MOSPI) for different years.

Fuel price index: ATF price has a direct influence on its consumption. The price of ATF is represented by its Wholesale Price Index. Wholesale price index (WPI) represents the growth of industry and measures the inflation over the period. WPI works as an important price index to showcase the overall macroeconomic picture of the country. Data on WPI of ATF is collected from Energy Statistics, MOSPI for different years.

CO_2 emission: The variable CO_2 emissions have been calculated by the authors using the conversion formula provided by the IPCC report, 2011. According to this report, per tonne of ATF emits 3.157 tonne of CO_2. Using this formula, the total quantity of ATF consumption for each year is multiplied with 3.157 tonnes to find out total CO_2 emission. Though there are many other pollutants, only CO_2 emissions are considered primarily because it is having a high composition to total pollution. Emissions from aviation turbine fuel are comprised of approximately 70 % CO_2, 30% water vapour and less than 1% of other emissions.

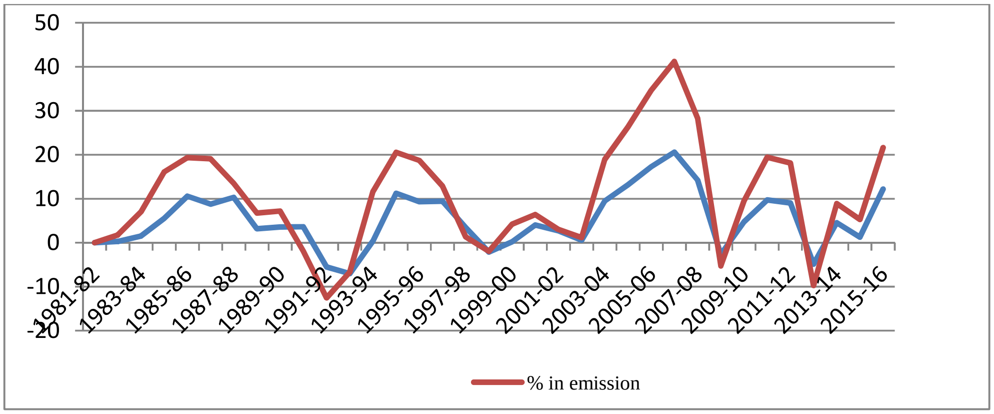
Revenue passenger kilometer: It measures the number of kilometers travelled by revenue paying passengers. It is calculated as the total number of revenue paying passengers multiplied by the total distance travelled. Revenue passenger kilometer is a measure of the actual demand for the air transportation. It shows the total sales volume of passenger traffic. It has been commonly used as the output of the aviation industry for estimation purpose.

Per capita income: The growing middle class is considered as one of the factors that propel the demand for the air transportation industry in India. Per capita income has been taken as a variable that represents the growing demand for air traffic.

After defining the important variables considered for the study, the econometric model is constructed. This study considered CO_2 emissions as a dependent variable, while revenue passenger kilometer, price index of fuel, efficiency of fuel and per capita income are considered as independent variables. The variable of fuel consumption is being opted out from the empirical model due to the reason that consumption is a function price and they cannot be a part of same equation as explanatory variables. Instead of that, we have calculated the **efficiency of aviation turbine fuel** as the ratio of kilometers flown by the passengers which represents the consumption of fuel.

Fuel price and fuel consumption cannot be used together in one equation as independent variables because both price and consumption are function of each other. So we have plotted a trend analysis between dependent variable emissions and independent variable fuel consumption. The time duration has been taken for the trend analysis is 1981 to 2016.

Figure 2: The Relationship between Emissions and Fuel Consumption



Source: Author's calculation using MOSPI for various years

X-axis represents the time period from 1981 to 2016 and **Y-axis** represents the growth rate of CO_2 emissions and growth rate of aviation turbine fuel consumption. In line with the tremendous growth of air transportation in India, the consumption of ATF in India went up by 40 per cent from 3.3 million tonnes to 4.6 million tonnes between 2005 and 2010 (Arushi, 2011). There is a direct relationship between CO_2 emissions from airlines and their consumption of fuel. We have calculated the percentage change in fuel consumption and emissions. The trend above shows that percentage change in CO_2 emissions and percentage change in fuel consumption follows the similar pattern but CO_2 emissions is much higher than consumption of fuel.

The following table provides descriptive statistics of the main variables.

Table 2: Descriptive statistics of the variables

Variables	Mean	Median	Maximum	Jarque-Bera	Probability
Emissions	10.88	7.50	24.08	3.422	0.180
Efficiency	113.39	112.86	179.16	2.785	0.248
PCI	30871.4	25119.5	62141	3.358	0.186
RPK	60727.87	30670.5	199409.	5.708	0.057
WPI	115.7599	86.559	274	3.067	0.215

Source: Authors' calculation

Before moving on to the time series econometric analysis, a descriptive statistical analysis has been carried out. Jarque-Bera is a test statistics for testing whether the series is normally distributed. The null hypothesis for Jarque-Bera test is: data is normally distributed and the alternative hypothesis is data is not normally distributed. Reported probability is the probability value Jarque-Bera test exceeds the observed value under the null hypothesis. We accept the null hypothesis when p-value is greater than 0.05 and reject it otherwise. From table 2, probability values of RPK, WPI of ATF, Efficiency, PCI and emissions are greater than 0.05. So we accept the null hypothesis concluding that data is normally distributed. For GDP-per capita and WPI of ATF, probability value is greater than 0.05 and hence we accept the null hypothesis. As the numerical range of our data set varies from crore to index values, for the purpose of smooth estimation, we have taken the logarithm form of all the variables.

Unit Root Test

There are several of methods to carry out the unit root test; among these ADF test method is employed to identify the order of integration of each variable. All the test of unit root will have null hypothesis of unit root, whereas the alternative hypothesis is time series may not contain a unit root. The following table represents unit root test results for all the variables:

Table 3: Unit root test

Variables	ADF test statistics (level) p-value	ADF test statistics (1^{st} difference) p-value
Logefficiency	0.7032	0.0021
logWPI	0.1182	0.006
logRPK	0.4945	0.0460
logemissions	0.0968	………
logPCI	0.8870	0.0005

Source: authors' calculation

Unit root test results show that all the selected variables of the study have a mixed order of integration; WPI of ATF, Revenue Passenger Kilometer, Per Capita Income and fuel efficiency are integrated at order one. The variable CO_2 emission from ATF is stationary at level. Before moving ahead with the methodology for any time series analysis, the first step to be done is checking the stationarity of the variables. The result of the unit root test shows that we have variables with a mixed order of integration and the appropriate methodology is Auto regressive distributed lag model (ARDL) with Bound test approach.

ARDL Model

Result of Bound test indicates if there is a long run relationship between the variables. Autoregressive distributed lag model (ARDL) analyses the short run and long run dynamics of economic growth. To see the long run relationship among the variables, the widely used econometric technique is the co-integration method. But the Johensen co-integration test cannot be applied directly if variables of interest are of mixed order of integration, as this method requires all the variables to be I(1). An ARDL model is aOrdinary Least Square (OLS) based model which is applicable for all the variables in a model that are I (1) or I (0) as well as time series with amixed order of integration. ARDL model has advantage over other time series model in case of a small sample size. In this paper, ARDL model is used to study the relationship between CO_2 emissions, fuel price, fuel efficiency and output of air transport industry is estimated using ARDL model with Bound test approach. The empirical model is defined as below:

$$\text{Log}(\text{EMISSION}_t) = \beta_0 + \beta_1 \text{Log}(\text{RPK}_t) + \beta_2 \text{Log}(\text{WPI}_t) + \beta_3 \text{Log}(\text{EFFICIENCY}_t) + \beta_4 \text{Log}(\text{PCI}_t) + U_t \quad \text{..(1)}$$

In the equation (1), log emission is the dependent variable representing CO_2 emissionsfrom the consumption of ATF. RPK represents revenue passenger kilometer. WPI represents wholesale price index of aviation turbine fuel. Efficiency represents fuel efficiency of aviation turbine fuel and PCI represents the GDP per capita of the country at constant price of 2004-05.

The Econometric Model

Considering the above advantage of ARDL approach over the co integration approach, we specify the following equation:

For the short run analysis, the equation is as follows:

$$\Delta Log(EMISSIONt) = \alpha 0 + \sum_{i=1}^{p} \alpha 1i\Delta\,(\mathrm{Log}\,Emission)t - i + \sum_{i=0}^{q1} \alpha 2i\Delta(\mathrm{LogRPK})\mathrm{t} - \mathrm{i} + \sum_{i=0}^{q2} \alpha 3i\Delta\,(\mathrm{LogEfficiency})\mathrm{t} - \mathrm{i} + \sum_{i=0}^{q3} \alpha 4i\Delta(LogWPI)t - i + \sum_{i=0}^{q4} \alpha 5i\Delta(LogPCI)t - i + \beta 1(LogEmission)t - i + \beta 2(LogRPK)t - i + \beta 3(LogEfficiency)t - i + \beta 4(LogWPI)t - i + \beta 5(LogPCI)t - i + Ut \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

In the equation (2), Δ is the first difference operator, q is the optimal lag length, α1i, α2i, α3i, α4i and α5i represent the short run dynamics of the model and β1, β2, β3, β4 and β5 represents the long run dynamics of the model.

To check the causal relationship among the variables, the study is adopting the Toda-Yamamoto test for causality.

Selections of Optimum Lag Length

To select the lag length of the model, Akaike Information Criterion (AIC), Schwarz Criterion (SC) and Henna-Quinn (HQ) are tried. For a correct model specification, prior to the estimation, we must specify the length of the lag. Lag length of the model is selected through. Butthe most commonly used lag length by information criterion are the AIC and the SIC. Therefore this study adopts the AIC.

Table 4: Selection of optimum lag length

lag	LogL	LR	FPE	AIC	SIC	HQ
0	71.33524	NA	5.05e-09	-4.913721	-4.673751	-4.842366
1	205.4152	208.5688	1.63e-12	-12.99372	-11.55390*	-12.56558
2	241.8072	43.13134*	8.65e-13*	-13.83757*	-11.19791	-13.05266*

Source: Authors' calculation

According to the Akaike information criterion (AIC), the optimum lag length is 2. Lower AIC means the model is considered to be close to the truth.

An error correction version of equation (2) is

$$\Delta(LogEMISSION)t = \alpha 0 + \sum_{i=1}^{p} \alpha 1i\Delta(LogEMISSION)t - i + \sum_{i=0}^{q1} \alpha 2i\Delta(LogRPK)t - i + \sum_{i=o}^{q2} \alpha 3i(LogEfficiency)t - i + \sum_{i=0}^{q3} \alpha 4i(LogPCI)t - i + \sum_{i=0}^{q4} \alpha 5i\Delta(LogWPI)t - i + \lambda ECt - i + €t \ldots\ldots\ldots..(3)$$

In the equation (3), λECt-I represents the error correction term which tells about the speed of adjustment towards the long run equilibrium.

Bound Test for Long Run Relationship

In order to find out the long run relationship, we conduct Bound test for equation (2) with two bounds that is lower bound and upper bound. Co-integration test is run on the long run co-efficient of the variables. The null hypothesis assumes no co-integration among variables. If the calculated value of F statistics comes more than the upper bound value, then there is co-integration and if the F statistics value is less than the lower bound, then the null hypothesis is accepted stating no co-integration exists (Audi, 2016).

Hypothesis set for the Bound test

H0: β1=β2=β3=β4=β5=0

HA: β1 ≠β2 ≠β3 ≠β4 ≠β5 ≠0

Table 5: Bound test result for ARDL (2, 0, 0, 1, 0)

F-Bounds Test		**Null Hypothesis: No levels relationship**		
Test Statistic	Value	Signif.	I (0)	I (1)
			Asymptotic: n=1000	
F-statistic	13.90608	10%	2.2	3.09
K	4	5%	2.56	3.49

Source: Authors' calculation

We applied the Bound test to see either co-integration exists or not. From the above table represent the Bound test result. The rule of thumb is that value of F statistics is more than the both upper bound I(1) and lower bound I(0). Here, we reject the null hypothesis with two bounds and conclude that there is co- integration among the selected variables of the study.

Analysis of Empirical Results

Estimation of Long Run Co-efficients

The empirical result of the long run estimation of ARDL (2, 0, 0, 1, 0) shows that revenue passenger kilometer and per capita income are positively related to the variable CO_2 emissions and it is highly significant. Efficiency of fuel is also significant and it is negatively related to CO_2 emissions. Long run estimation result shows variable wholesale price index of aviation turbine fuel is insignificant in relation to CO_2 emissions.

Table 6: Long run co-efficient of ARDL (2, 0, 0, 1, 0)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGRPK	0.405356	0.064811	6.254459	0.0000
LOGWPI	0.012721	0.028396	0.447983	0.6592
LOGEFFICIENCY	-0.107080	0.031434	-3.406553	0.0030
LOGPCI	0.332525	0.120394	2.761982	0.0124
C	-5.101055	0.566782	-9.000038	0.0000

Source: Authors' calculation

Table 6 represents the long run coefficients of ARDL (2, 0, 0, 1, 0) where the dependent variable is Log-emission. Co-efficient of RPK indicates that 1 per cent increase in RPK leads to 0.4 per cent increase in the CO_2 emissions. Fuel efficiency is inversely related to CO_2 emissions. One per cent increase in fuel efficiency leads to a decrease in CO_2 emissions by 0.10 per cent. Increase in fuel efficiency always reduces the CO_2 emissions.

Co-efficient of PCI shows that one per cent increase in PCI leads to increase in the CO_2 emissions on an average by 0.33 per cent at one per cent level of significance. Co-efficient of WPI of ATF is insignificant inthe long run with a probability value of 0.65.

Estimation of Short Run Co-efficients

Now turning to the short run results of estimation, it also shows that except the variable wholesale price index of ATF, all other variables are significant. The error correction term is also significant with a probability value of 0.000.

Table 7: Short run co-efficient of ARDL (2, 0, 0, 1, 0)

Conditional Error Correction Regression				
Variable	Co-efficient	Std. Error	t-Statistic	Prob.
C	-5.013511	0.786521	-6.374285	0.0000
logEMISSION(-1)*	-0.982838	0.123029	-7.988647	0.0000
logRPK**	0.398400	0.081173	4.908036	0.0001
logWPI**	0.012503	0.028097	0.444986	0.6614
logEFFICIENCY**	-0.105243	0.038383	-2.741911	0.0130
logPCI(-1)	0.326818	0.124396	2.627244	0.0166
D(logEMISSION(-1))	0.540951	0.103525	5.225297	0.0000
D(logPCI)	0.806428	0.281855	2.861143	0.0100
Co-intEqn(-1)	-0.98283	0.09573	-10.2661	0.000

Source: Authors' calculation

In the short run, one per cent increases in efficiency of fuel leads to the reduction of CO_2 emissions by 0.10 percent. Co-efficient of RPK indicates that one per cent increase in RPK leads to increase in CO_2 emissions by 0.39 percent. PCI is also positively related to CO_2 emissions, indicating one per cent increase in PCI leads to increase in emissions by 0.32 percent. WPI of ATF is insignificant with a probability value of 0.66. WPI of ATF is insignificant in relation to CO_2 emissions in the short run also.

Co-integration equation in table 7 represents the error correction term which indicates the speed of the adjustment process from previous year's disequilibrium in CO_2 emissions from ATF to the current year. Error correction term is also statistically significant. The adjustment speed is as high as 98 percent.

After estimating the relationship between dependent variable and independent variables for both short run and long run ARDL model, we can draw the following inferences:

Revenue passenger kilometer of airline industry is considered to be the output of the industry which has a direct relationship with the demand for air travel and increased passengers. So, the mechanism is very simple indeed- an increased number of passengers leads to increased demand for air travel which in turn leads to increase in the revenue passenger kilometer by having the requirements of more number of air fleets. More number of air fleets in the operation requires more consumption of aviation turbine fuel leading to more of CO_2 emissions.

Per capita income is considered as a variable that represents the growing middle-class population of India. With the continuous increase of per capita income, by adopting air travel as a mode of transportation, the growing middle class is contributing towards an increase in output of the industry which eventually leads to more of carbon emissions.

Fuel efficiency is inversely related to CO_2 emissions. There are many factors in airlines that lead to the efficiency of fuel over the years. Energy efficiency of theaviation sector has seen a significant improvement since 2000. Globally, the fuel efficiency of aviation turbine fuel increased by 2.9% per year during 2000-16 (Jacob Teter, 2019). Low cost airlines are increasing the average number of passengers per flight which is lowering the energy use per passenger. Another driver of increased energy efficiency is fleet renewal with more technologically advanced planes. In the year 2016, Indigo was the first Indian carrier who took delivery of new engine technology aircraft A320 neo in its fleet to increase efficiency of fuel (Chowdhury, 2016).

As our estimation shows, for both the short run and long run, WPI of ATF has insignificant impact on CO_2 emissions. Fuel price constitutes around 40 per cent of the total operating cost for the airline industry (Anirban Chowdhury, 2019). The industry is known for its high cost and low yields. Though fuel expense covers a major portion of the operating cost, it is difficult for airlines to adjust with the consumption of fuel considering the growing demand for air transportation. Increased fuel prices make airline industries suffer from losses, but it does not have any impact on the reduction of CO_2 emissions.

From the above analysis, we conclude that the estimated result of the ARDL model for both short run and long run explains the strong relationship between dependent variable and independent variables. But it does not explain the direction of causality. To check the causality among the variables, we have adopted the Toda-Yomamoto test over the traditional Granger Causality test. The following tests are carried out to check the stability of the model:

Result of Diagnostic Test

CUSUM and CUSUMQ Test

We tested the stability of the selected ARDL model based on error correction model using the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) using the stability testing technique presented by Brown *et al* 1975 (Pham Dinh Long, 2018). CUSUM and CUSUMSQ plots have been shown in figure 4 and figure 5 below:

Figure 4: Cumulative Sum of Recursive Residuals

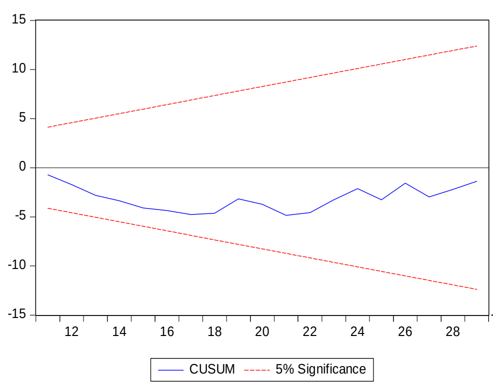
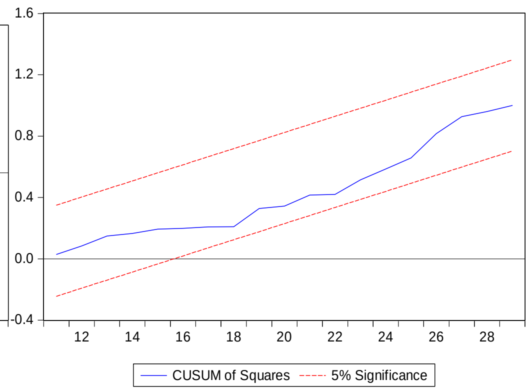


Figure 5: Cumulative Sum of Squares of Recursive Residuals



The basic purpose of verifying the CUSUM and CUSUMSQ is to check if the model has any structural break or instability. The rule of thumb is if both the plots remain within the critical bounds at 5 per cent level of significance, we can conclude that the model is structurally stable. Our analysis shows that for both CUSUM and CUSUMSQ test, the plot remains within the critical bounds; hence concluding that our ARDL model with Bound test approach is structurally stable.

Serial Correlation Test

The problem of serial correlation occurs when the error term observations in a regression model are correlated. Serial correlation will not affect the unbiasedness and consistency of the OLS estimator, but it affects their efficiency. In the presence of serial correlation, we conclude that parameter estimates are either less precise or more precise than they actually are. To avoid this problem, we check if there is any serial correlation in the error term by setting a null hypothesis with no serial correlation. The following Breusch- Godfrey serial correlation result shows that the probability value is 0.29. Since probability value is greater than 0.05, we accept the null hypothesis stating that there is no serial correlation in the error term of the model.

Null hypothesis is there is no correlation, and we accept the null hypothesis only when probability value is more than 0.05.

Table 8: Breusch-Godfrey Serial Correlation LM Test

F-statistic	1.297886	Prob. F(2,17)	0.2988
Obs*R-squared	3.576581	Prob. Chi-Square(2)	0.1672

Heteroscedasticity Test

One of the important assumptions made by the classical linear regression model is that the error term should be homogeneous in nature. Violation of this assumption leads to the problem of heteroscasticity. The presence of heteroskedasticity affects the estimation and test of hypothesis. To avoid this problem, we test Breusch-Godfrey test for heteroscadsticity. Null hypothesis set for the test is that there is no heteroscedasticity. Probability value of the test is 0.06 which is greater than 0.05. Since the probability value is greater than 0.05, we accept the null hypothesis and say that there is no heteroscedasticity.

Table 9: Test Breusch-Godfrey test for heteroscadsticity

F-statistic	2.545379	Prob. F(7,19)	0.0699
Obs*R-squared	13.06647	Prob. Chi-Square(7)	0.0705
Scaled explained SS	4.665716	Prob. Chi-Square(7)	0.7007

Toda – Yomamoto Test for Causality

Toda-Yomamoto(T-Y) test has certain advantages over the traditional Granger Causality test. For testing T-Y, there are no restrictions that variables must be at level or first difference or second difference. T-Y test is valid whether a series is I (0), I (1) or I (2), non co-integrated or co-integrated in any uniformed order. This approach makes the causality test much easier because in this technique, researchers have no need to test co-integration or convert VAR into ECM.

T – Y test for causality follows the following steps:

1. Finding the order of integration (d) of variables by conducting the unit root test
2. Next step is to determine the optimum lag length (k) of a VAR.
3. Estimating the lag – augmented VAR (k+d) model.
4. Checking the robustness of augmented VAR(k+d) by diagnostic test
5. Conducting a Wald test on the first k parameters instead of on all parameters in augmented VAR (k+d) model.

Empirical Results of the T-Y Causality

To proceed with the T-Y test for causality, we have determined the maximum number of lag to be 2. The optimum lag length is based on Akaike Information Criterion (AIC). The result of the Granger-Causality test is given below in table 10.

Table 10: T-Y causality results

Dependent variable: logEmission			
Excluded	chi-sq	df	prob
logRPK	35.72	2	0.0000
logEfficiency	20.24	2	0.0000
logPCI	10.74	2	0.0047
logWPI	8.326	2	0.0156
Dependent variable : logRPK			
Excluded	Chi-sq	df	prob
logEmission	4.5894	2	0.1008
logEfficiency	6.0489	2	0.0486
logPCI	5.0942	2	0.0783
LogWPI	1.3922	2	0.4985
Dependent variable : logPCI			
Excluded	Chi-sq	df	prob
logEmission	13.4102	2	0.0012
LogRPK	1.70581	2	0.4262
logPCI	11.0780	2	0.0039
LogWPI	0.83361	2	0.6591
Dependent variable : logPCI			
Excluded	Chi-sq	df	prob
logEmission	30.2545	2	0.0000
logRPK	34.6042	2	0.0000
logEfficiency	45.2434	2	0.0000
logWPI	5.87954	2	0.0529
Dependent variable : logWPI			
Excluded	Chi-sq	df	prob
logEmission	1.27708	2	0.5221
logRPK	3.82297	2	0.1479
logEfficiency	6.58486	2	0.0372
logPCI	1.12369	2	0.0570

Source: Authors' calculation

Empirical result shows that revenue passenger kilometer causes CO_2 emission. There is a unidirectional causality from revenue passenger kilometer to CO_2 emission.

There is bi-directional causality existing from emissions to efficiency and efficiency to emission. CO_2 emissions does Granger cause fuel efficiency and fuel efficiency does granger cause CO_2 emission.

We see that there is bi-directional causality existing from emissions to per capita income and per capita income to emissions. Both the variables are Granger causing each other.

T-Y Granger causality test shows that there is a unidirectional causality from WPI to CO_2 emissions but CO_2 emissions do not Granger cause WPI of aviation turbine fuel.

Conclusions and Implications

This study analyzed the relationship between fuel price, fuel efficiency, aviation growth and CO_2 emissions from 1988 to 2017 using ARDL model of Bound test approach. To test the causality among the variables, Toda-Yamamoto test is performed, keeping its advantage over the traditional Granger causality test.

The findings of our study show that the growing passenger demand and per capita income lead to more CO_2 emissions whereas fuel efficiency has also been increased over the time by reducing CO_2 emissions from airlines during the period 1988-2017. Another important finding of our study is WPI of ATF is insignificant to CO_2 emissions. The possible reason can be, due to the unprecedented and increased demand of air travel in India, demand for ATF is also continuously increasing, but the improved efficiency of fuel is controlling the emissions from its increased consumption.

The Director General of Civil Aviation released the first ever report on aviation carbon footprint in the year 2011 and the report states that Indian airlines flying within the country and abroad account for less than one per cent of the country's total CO_2 emissions. Though carbon emissions from the Indian airline industry are less than the global average, in the absence of monitoring, carbon emissions from domestic aviation will be double and will increase by 20 times in international routes by 2020 (Radhakrishnan, 2015). Aviation has been able to achieve substantial efficiency improvements, but the gains have regularly been offset by even number of traffic growth. Efficiency of fuel is an important determinant when it comes to reducing CO_2 emissions through the consumption of ATF. The major reason for the improvement of energy efficiency can be considered as adopting aircraft with improved technology which has reduced the amount of fuel consumption. Much of the debate within ICAO on establishing goals to reduce the international aviation impact on climate change has focused on improving fuel efficiency. At the present time, ICAO has endorsed a goal of an annual 2% improvement in fuel efficiency up to the year 2050 (Environmental report, 2016).

It's important for Indian policy makers also to think on similar lines by improving aircraft technology to support the growth of the industry but at the same time making sure that the growth is sustainable enough without compromising with the growing environmental concerns.

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