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Is the long-run Demand for Air Transportation Set to Grow? An Empirical Analysis of the US Domestic Air Travel Demand

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The aviation industry holds immense importance in the United Sates since it plays a pivotal role in economic growth and development. However, to make the aviation industry work at the best of its possibilities, an accurate forecasting of air passenger demand is crucial both in the short and in the long term. Focusing on the long term, according to the Federal Aviation Administration's projections, the domestic air travel demand in the US is expected to grow at rates of about 2.6% per annum for the next 20 years. These projections may derive from an optimistic approach on the evolution of key variables that influence the air travel demand. By using a reduced form model which includes the national Gross Domestic Product and airline ticket prices, and by including factors which are usually overlooked when forecasting air travel demand such as the impact of climate change, the fiscal imbalance, and the increasing income inequality, this paper investigates whether the Federal Aviation Administration projections can be considered as realistic or not. Although some limitations, this paper finds that the Federal Aviation Administration's projections slightly overestimate the air travel demand growth and that the effects of the above-mentioned factors will be limited. Moreover, this paper provides some preliminary qualitative insights in terms of policy implications and underlines the areas in which further research is expected in the future.

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1. INTRODUCTION

The aviation industry holds immense importance in the United Sates; it plays a pivotal role in economic growth and development, it creates jobs, and it serves as primary means of global connectivity enabling transportation of goods, people, and ideas worldwide. In numbers, in 2016, the aviation industry directly and indirectly contributed to more than 1.8 trillion in economic activity (around 5.2% of the national GDP) and supported more than 10.9 million jobs. (FAA 2020).

However, for the whole aviation industry to work at the best of its possibilities, an accurate forecasting of the demand for air transport is of crucial importance both in the short and in the long-term. In the short term, when supply is almost fixed, airline companies rely on accurate forecasts for more immediate concerns including resource planning (namely, allocation of aircrafts and crew members), revenue management (namely, optimizing pricing strategies) and to increase the operational efficiency (Tsui et al. 2014). In the long term, accurate forecasts are crucial for fleet planning (namely, fleet expansion or retirement), infrastructure development (runway expansions, terminal enhancements, and airport construction), and strategic decision making (namely, identifying new routes and markets) (Jin et al. 2020).

Although the importance of a precise prediction is clear, it is way less clear how to carry out these forecasts. As a matter of fact, it is a very challenging job to predict the air passenger demand due to its multiple characteristics, such as irregularity, high volatility, and non-stationarity (Xiao et al., 2014). Therefore, in order to (at least partially) overcome these issues, all kinds of models have been built up to forecast passenger demand and most of them can be classified in three main categories: time series analysis models, artificial intelligence models and economic models (Dantas et al. 2017). While time series analysis and artificial intelligence models provide accurate results in short-term forecasting, economic models tend to provide more accurate results in the long term.

For the US aviation market, which is the second biggest civil aviation market in the word, the reference point for long term forecasting is provided by an economic model developed by the Federal Aviation Administration (FAA). To be more specific, on an annual basis, the FAA publishes the "FAA Aerospace Forecast" to provide insights into the projected growth and trends in the U.S. aerospace industry and, according to the latest estimation, the domestic air travel demand in the US is expected to grow at rates of about 2.6% per annum for the next 20 years (FAA 2022).

However, in a period strongly characterized by demand uncertainty and optimism bias (Suh & Reyerson 2019), the question becomes whether these forecasts are reliable or not. While in the past the ever-increasing Gross Domestic Product (GDP) growth rate, the decreasing cost of air travel, the higher discretionary incomes, the improved levels of education, the population growth, and the increasing urbanisation rate were all signals that (correctly) led to hypothesize a growth in the air travel demand, the evolutions of some of these factors in the future has the potential to undermine the air passenger demand growth. Moreover, another important, yet overlooked, factor that has the potential to reduce the air travel demand growth is climate change. In fact, while the effects of the aviation industry on climate change have been extensively explored within the academic literature, the effects of climate change on air travel demand have been so far largely understudied.

Given all these different factors, the main purpose of this paper is to contribute to the existing literature by further exploring the potential impact of drivers that are typically not included in aviation projections and by providing an assessment of how plausible long-term trends in key variables (namely, GDP and airfares) might affect the air travel demand in the long term. In order to do so, basing on a similar approach used to estimate the global air travel demand evolution (Becken & Carmignani 2020), an economic (reduced-form) model is built to forecast the evolution of the US domestic air travel demand from 2023 to 2050. Then, the effects of climate change (namely, physical costs, mitigation costs, and the insurgence of infectious disease), the increasing income inequality, and the fiscal imbalance of the US government are taken into account to correct the expected GDP growth. It is worth underlying that given the overall simplistic approach, the purpose of this paper is not to provide a definitive alternative to other, more rigorous, quantitative forecasts, but it should rather be interpreted as a sensitivity analysis that allows for an analysis of factors which risk remaining unrecognised due to overly optimistic approaches.

The rest of the paper is organized as follows. Section 2 provides the theoretical basis on which the empirical model will be based. Section 3 describes the data, the empirical model and the choice made in the calibration stage. Section 4 presents the results, the policy implications, and the areas in which further research is expected in the future. To conclude, Section 5 presents the conclusions.

2. MODELLING FRAMEWORK

Given the limitations of time series and artificial intelligence models as long-term forecasting tools, a reduced-form economic model is built to predict the evolution of air travel demand in the US. From a theoretical point of view, the model that will be used to forecast the US domestic air travel demand is relatively simple: the air travel demand has been determined in the past by the Gross Domestic Product and by the price of tickets (namely, airfares) and the main assumption is that these same drivers will influence the evolution of domestic air travel demand in the future as well. However, while the evolution of the prices of airline tickets is likely to remain mostly determined by crude oil prices, labour costs, and aircraft efficiency, the expected gross domestic product growth risks to be influenced by different factors which are largely overlooked within the air transport research community including physical costs, mitigation costs, and costs arising from the insurgence of new infectious disease, fiscal imbalance, and income inequality. In addition to slowing economic growth, the physical effects of climate change, the insurgence of new disease, and a greater income inequality risk to affect the overall air travel demand as well. All the above-mentioned causal relationships, shown graphically in Figure 1, are discussed in detail in this section.

2.1 The demand for air travel

As stated in the introduction, the purpose of this paper is to build an economic reduced-form model able forecast the evolution of the domestic air travel demand in the United States for the next 27 years. To build this model, a preliminary step consists in identifying the factors that will drive the US domestic air travel demand in the future. Although decades of research illustrate the great variety of factors influencing air travel demand (Wang & Song 2010, Wang & Gao 2021) including tourism-related factors (Boonekamp et al. 2018), labour-related metrics (Carmona-Benítez et al. 2017), foreign investments (Valdes 2015), exchange rates (Chen et al. 2012), and airline operational factors including flight connectivity (Hazeldine 2017), frequency of flights (Hsiao & Hansen 2011), on-time performance (Hsiao & Hansen 2011), and the duration of flights (Li et al. 2013), two drivers stand out for their systematic dominant influence on the passenger demand, namely the price of airfares and people's income.

The significance of these two factors in shaping air travel demand is readily evident; as consumers experience an increase (decrease) in their income, their purchasing power rises (decreases), enabling them to allocate a larger (lower) portion of their budget to discretionary expenses such as travel. In the same way, when airfares become more (less) affordable, a wider (smaller) segment of the population gains access to air travel, thereby stimulating (reducing) demand.

After identifying the relevant drivers, it is also necessary to discuss (and then estimate) the elasticities of air travel demand with respect to these factors. In this specific case, demand elasticities measure the change in the quantity demanded of air travel services in response to changes in airfares and consumers' income. Although many scholars tried to assess the elasticities of demand with respect to these factors, elasticities values found within the academic literature tend to be extremely discordant (Brons et al. 2002, Mumbower et al. 2014, Morlotti et al. 2017). These discrepancies can depend, among other things, on the techniques used to estimate the elasticities, the data used to carry out the analysis, on the country on which the analysis is based (namely, developed or developing country), the type of traveller analysed (namely, leisure, business, or bleisure traveller), or the type of route (namely, short-, medium, or long-haul routes).

2.2 Gross Domestic Product and Long-term Headwinds

Since the economic growth forecasts are always expressed in terms of real GDP growth reduction, following many previous studies (Marazzo et al. 2010, Suryani et al. 2010, Hanson et al. 2022), this paper uses the national real GDP as a proxy for the level of income in the US and crude oil prices as a proxy for the jet fuel prices. The main advantage of this choice is that by using the GDP, it is possible to define the impact of other factors which are likely to reduce the economic growth.

To be more specific, typically, long term GDP projections relies on a decomposition of the GDP growth rate into its proximate determinants, namely technological progress, labour accumulation, and physical capital accumulation. Technological progress is modelled assuming that the rate of productivity growth will converge to some exogenous steady state value. Labour accumulation is derived from the analysis of trends in working-age population and from the employment rate of different groups. To conclude, physical capital accumulation is obtained from a projection equation that incorporates convergence towards a stable capital to output rate after accounting for inertia, depreciation, and constraints arising from factors like current account imbalances or cyclical conditions.

However, this decomposition process does not consider additional headwinds which can systematically affect the economic growth in the long term. In particular, even by assuming that the rate of productivity growth continues at the same rate of the last thirty years, the economic growth in the US is likely to be affected by different factors including the negative effects of climate change, the government fiscal imbalance, and the increasing income inequality (Gordon 2012, Gordon 2014).

Since the effects of climate change are numerous and multifaceted, in this paper, three different impacts of climate change on economic growth and on air travel demand will be taken into account, namely the costs arising from physical effects of climate change (physical costs), the costs of a net-zero transition (mitigation costs), and the costs connected with emergence of infectious disease.

The first significant concern associated with climate change are the physical costs arising from the physical effects of climate change. To be more specific, physical costs derive from extreme weather events, which include the increasing in frequency and severity of natural disasters (such as floods, wildfires, cyclones, droughts), and from long-term shifts, which refer to the change in trends of weather patterns (such as the sea level rise or the average increase in temperatures) and these costs have the potential to impact both the overall economy and the air travel demand. In the first case, extreme weather events and long-term shifts have the potential to weaken economic growth through damage to the capital stock and labour supply while in the second case these phenomena can lead to flight delays and cancellations and damage or loss of infrastructure.

The second major concern associated with climate change are the costs of a net-zero transition. A growing number of governments and companies are pledging net-zero emissions by 2050 to reach the objectives of the Paris Agreement. However, although being a necessary process to limit global warming and the negative effects of climate change, achieving this transition brings with it a complete paradigm shift from fossil fuels to renewable sources of energy which requires massive investments (in the order of billions of dollars) in research, development, and deployment of low-carbon technologies.

The last significant concern associated with climate change is the latter favouring the insurgence of infectious disease. Over the last few years, an ever-increasing number of articles underline how emerging infectious diseases are a growing threat to global health, economy, and safety. To be more specific, warmer temperatures, altered precipitation patterns, extreme weather events, and air pollution, besides being hazardous for health, have the potential to cause a reduction in economic growth due to losses in human capital and reductions in productivity. In addition to this, as was the case of Covid-19, new infectious disease can lead governments to adopt draconian measures (including restriction on human mobility) which can directly negatively affect the air travel demand.

The second headwind is the risk of worsening fiscal imbalance, particularly in the form of increasing levels of net public debt. Whether public debt influences or not economic growth is one of the oldest and most debated topics in macroeconomics. Some articles point out that public debt decreases economic growth only when the former exceeds a limit threshold (fixed in most cases to 90% of the GDP) while others suggest that the problem it's not the quantity of debt itself but rather the quality of the debt (for example, if country issuing the debt is politically stable or not). Despite these inconsistencies, most studies agree that the absence of an universal threshold or an unambiguous explanation on the impact of debt on economic growth does not imply that public debt can grow indefinitely without consequences. In support of this thesis, many articles underline how, among other things, a persistent high level of public debt can consequently trigger detrimental effects on capital accumulation and productivity, which potentially has a negative impact on economic growth (Kumar & Woo 2010, Mencinger et al. 2014).

The third and last headwind which could decrease the US long term economic growth is the income inequality distribution within the country. As for the relationship between economic growth and fiscal imbalance, economic theory supports conflicting narratives about the potential impact of economic inequality on growth (Shin 2012). Some articles suggest that greater income inequality tends to reduce economic growth in the long term because of a reduced aggregate demand (since most people will have less disposable income to spend), higher barriers to accessing economic opportunities (such as education, credit, and healthcare for the poorest segment of the population), and higher social and political instability, while other papers affirm that income inequality can increase economic growth because of higher capital accumulation and investments (Mdingi & Ho 2021). However, as for the level of public debt held by governments, most articles agree that income inequality cannot grow indefinitely without economic consequences.

To reconcile these discordant theories, some studies suggest the possibility of an inverted U-shaped relationship between income inequality and economic growth where the former can bring benefits for the economy if kept at controlled levels, as in advanced economies, while it can reduce economic growth if not contained, as in developing countries (Chen 2003). Interestingly, because the level of income inequality in the United States is approaching heights generally only found in the developing world, the trends identified for developing countries may be more applicable than those of developed nations (Boushey & Price 2014).

2.3 Airfares' determinants and the direct rebound effect

According to the same line of reasoning applied to define the air travel demand determinants, it is necessary to define which variables affect the prices of airline tickets. Although airline costs may change for various reasons, such as alternations in input prices, labour conditions, maintenance to the airplanes, taxation regimes and airport charges, the main cost sources for US airline companies are jet fuel costs and labour costs (IATA 2010). The significance of these two factors in shaping airline costs is readily evident; when jet fuel prices and labour costs rise, airlines face increased expenses, which can result in higher ticket prices for passengers. After identifying these drivers, it is also important to discuss the elasticities of airfares with respect to these factors. In this specific case, the elasticities measure the cost pass-through rate, namely by how much airlines increase airline ticket prices as a result of costs increase.

Another element which plays a crucial role both in environmental and operational terms in the aviation industry is the aircraft efficiency. In general, aircraft efficiency refers to the ability of an aircraft to accomplish a specific task with minimal use of resources, most of the time fuel, while maximizing the performance and minimizing emissions. Over the last few years, given the heavy fluctuations of fuel prices which significantly impacted airlines' profitability, the pursuit of efficiency has become crucial for airline companies (Baharozu et al. 2017). In fact, by improving aircraft efficiency, airlines can reduce their fuel consumption and lower their operational costs. In turn, this can potentially lead to reduced ticket prices for passengers, as airlines can pass on some of the savings achieved through greater efficiency.

To conclude, the last element taken into account is the direct rebound effect[1]. The direct rebound effects occurs when the increased energy efficiency of a process or technology leads to an increase in the overall consumption or use of that resource, offsetting some of the energy savings (Berkhout et al. 2000). In the aviation industry, as shown within the air transport research community (Evans & Schäfer 2013, Miyoshi & Fukui 2018), the same line of reasoning is applied; if there are improvements in aircraft efficiency (such as advancements in aerodynamics or better operational practices) and airfares become more affordable, a larger number of people may choose to travel by air and/or opt for more frequent trips increasing the overall air transport demand.

3. DATA AND METHODS

After establishing the theoretical framework, it is possible to discuss the data used for the analysis and the empirical model. To assess the elasticity values, the data on the US domestic air travel demand, real GDP, and crude oil have been retrieved from the FRED database, airfares have been retrieved from the Bureau of Transportation Statistic[2], and labour costs have been retrieved from the MIT Airline data project website[3]. Instead, in order to carry out the projections, values and estimations have been retrieved by different sources including reports issued by government organizations, and scholar articles.

[1] There exist three types of rebound effect: direct rebound effect, indirect rebound effect, and economy-wise rebound effect. However, in this paper, only the direct rebound effect is taken into account.
[2] https://www.bts.gov/air-fares
[3] https://web.mit.edu/airlinedata/www/default.html

3.1 Estimating Income and Price elasticities

In order to assess the air travel demand elasticities, an econometric regression with time series quarterly data spanning from 2003Q1 to 2019Q4 has been performed. In formal terms, the following reduced-form model has been used:

$$ln(Demand) = \alpha ln(GDP) + \beta ln(Airfares)$$

Where ln denotes the natural logarithms of Demand (namely, the total number of enplaned passengers for domestic flights), GDP (namely, the real GPD of the US) and airfares (namely, the average inflation-adjusted price of airline tickets for domestic flights). By using natural logarithms on both sides of the equation, the coefficients α and β respectively represent the elasticity of demand with respect to price and income. Although the elasticities obtained through the regression are statistically significant and both present the expected signs, their values (respectively 0.68 and -0.36) are slightly lower than expected, even if still in line with other values found within the academic literature. Moreover, given the maturity stage of the US aviation market, these values could reflect the fact that flights are not seen any more as luxury goods (namely, goods with an income elasticity higher than 1) but more as necessity goods (namely, goods with an income elasticity between 0 and 1). This same line of reasoning, combined with a lack of substitutes as means of transport in the US for medium and long distances, could therefore also explain why the air travel demand is inelastic to price (namely, with a value between 0 and 1).

3.2 Estimating the cost pass-through rate

In order to define the cost-pass through of airline companies, another econometric regression has been performed. However, although the time length still spans from 2003 to 2019, unlike the previous regression, data for crude oil price and labour costs were on an annual basis and they are not inflation adjusted. Therefore, in the projection stage, airfares have been projected in nominal terms and then they have been corrected for inflation in the projection stage. Formally, the reduced form model is:

$$ln(Airf) = ln(Oil) + ln(Wages)$$

Where ln denotes the natural logarithms of Airf (namely, the average price of airline tickets for domestic flights), Oil (namely, the Brent crude oil price) and Wages (namely, the average annual wages and salary for all employees in the aviation industry). In this case, by using natural logarithms on both sides of the equation, the coefficients α and β represent the cost pass-through rate. Once again, the elasticities obtained through the regression (respectively 0.12 and 0.20) are statistically significant, present the expected signs and are in line with the values found within the academic literature.

3.3 Defining GDP projections and long-term headwinds

Although the US economy is expected to grow in the next decades, the question is how much this growth will amount to. Most estimates agree on the fact that the aging population (and therefore a smaller working-age population), the level of technological maturity, and the productivity slowdown will make the economic growth slower than the one experienced in the past three decades. In numbers, while the US average GDP growth per annum of the last thirty years has been 2.4%, the expected GDP growth in the next three decades is expected to be around 1.7%. To be more specific, the real GDP growth is expected to be 1.9 for the decade 2022-2032, 1.6 for the decade 2033-2042 and 1.5 for the period spanning from 2043 to 2050 (CBO 2022).

In general, assessing the impact of climate change is, at best, an extremely complex exercise with uncertainty about both the degree of future global warming and the subsequent impact on the economic activity. However, in order to take into account all the potentials physical effects of climate change (positive and negative, direct and indirect, and immediate and gradual) in the US, the CBO developed a model that estimated that the effects of climate change will reduce the growth rate of real GDP from 2020 to 2050 by an average of 0.03 percentage points per year[4] (Hernstadt & Dinan 2020). Instead, with regard to the direct impact that climate change may have on the aviation industry, while there exist both qualitative and quantitative articles assessing the effects of single climate-related phenomena (Ryley et al. 2020), such as higher temperatures (Coffel & Horton 2015, Coffel et al. 2017) or flooding and droughts (Hu et al. 2016), on the aviation industry, no articles have been published so far providing a comprehensive analysis of the potential impacts that all the physical effects of climate change may have on the overall air travel demand. Therefore, no direct impact on the aviation industry has been taken into account.

With regard to the mitigation costs, the cost for a net-zero transition varies for every country due to several factors including the currant stage of economic development or the availability of renewable resources. However, in the case of the US, the latest estimation find that a successful net-zero transition could be accomplished at a net cost of around 0.7%[5] of GDP in 2050, which translates into an average GDP growth reduction of around 0.023% per annum, using only commercial or near-commercial technologies and requiring no early retirement of existing infrastructure (Williams et al. 2018). Although this value may seem lower than one would expect, also other studies found that a successful net-zero transition could be accomplished with an annual spending (as a percentage of GDP) on energy that is comparable, or lower, to what the United States already spends annually on energy today (Princeton University 2021)[6].

As for the physical effects of climate change, the insurgence of new infectious disease can have both indirect (through GDP) and direct effects (through restriction on human mobility) on air travel demand. Regarding indirect effects, while there is a consensus in the academic literature on the fact that climate change will favour the insurgence of new disease (Casadevall 2020), it is extremely difficult to define the

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[4] Although this model estimates both the positive and negative effects of climate change, it still presents some limitations. For example, the agency's projection does not fully account for potential effects on the U.S. economy from migration, social upheaval, and reduced economic performance in other countries due to climate change.

[5] This value represents an average of the different net costs estimated in the paper which in turn depend on different scenarios considered by the authors.

[6] It is important to note how these projections rely on the assumption that proactive policies and actions are implemented immediately without delaying the transition.

potential economics effects that new disease could have on the US economic growth. Basing on the branch of the literature that tries to assess the economic consequences of new disease outbreak, although new epidemics may cause short-term shocks (Meltzer et al. 1999, Prager et al. 2017), the potential effects of new disease on the long-term economic growth can be considered as negligible. Instead, with regard to the direct potential damages to the aviation industry (namely, new lockdowns and/or restriction to human mobility), it is worth noting that there are biological features of COVID-19 that have made the pathogen difficult to control, primarily the virus's ability to spread asymptomatically and presymptomatically. As a matter of fact, many pathogens do not exhibit these features, which may be a cause for cautious optimism going forward (Baker et al. 2022). Therefore, although it is true that new infectious diseases are likely to appear in the following decades and it true that their spread will surely be facilitated by the high degree of global interconnectivity (Findlater & Bogoch 2018), this kind of damages will surely be more contained than observed with COVID-19 and therefore they can be considered as negligible for the quantitative exercise performed in this paper.

Moving to the fiscal imbalance, in order to consider the effects of public debt on GDP, it has been first necessary to define the type of debt (namely, gross or net debt) taken into account and then to quantify its effects on the economic growth. Despite gross debt is a useful indicator when doing comparisons among different countries since it represents the overall size of the debt obligation without adjustments, net debt provides more information about a specific country since it allows to adjust the gross debt for the amount of debt held by the borrower (namely, the government). To be more specific, since part of the US government debt is held in the US Social Security Trust Fund, US statistical sources often use the "debt held by the public" that allows to net out these crossholdings.

To quantify the effect of debt on economic growth, it has been then necessary to define the projected evolution of the net debt and to calculate the elasticity. Some projections on the evolution of US the net debt have been performed by the CBO who estimated a net debt (as percentage of GDP) of 110% in 2032, 140% in 2042 and 175% in 2050. Since, as 2022, the debt held by the government amounts to 98% of the GDP, it is possible to assume that the "limit threshold" (fixed as assumption on 90%) has already been exceed and any further increase over the 98% will reduce the economic growth in future. To define the effects of the public debt on GDP, basing on similar values found within the academic literature (Kumar & Woo 2010, Woo & Kumar 2015), this paper assumes that a 10-percentage point increase in initial debt-to-GDP ratio is associated with growth slowdown around 0.1% in advanced economies. Therefore, the fiscal imbalance will reduce on average the GDP growth by 0.012% in the next ten years, by 0.03% from 2033 to 2042 and by 0.05% from 2043 to 2050.

To conclude, the same line of reasoning applied for the fiscal imbalance has been used to assess the negative effects of income inequality on economic growth, namely defining a tool to measure income inequality and then quantifying the effects of an increasing income inequality on economic growth. Although different tools exist to measure the inequality distribution within a country such as the Theil Index and the

90-10 ratio, the Gini coefficient is one of the most common measures of inequality because of its simplicity to compute. This index ranges from zero, representing perfect equality, to one hundred (or one), which represents complete concentration. According to the latest estimation, since even in a best-case scenario the income inequality distribution within the US is expected to increase (Rao et al. 2019), an increase of 1 point in the Gini index in the 27 years is a reasonable assumption.

In order to define the impact of the income inequality increase, basing on similar values found within the academic literature (Cingano 2014), this paper assumes that focusing on the on the long term a 1 Gini point increase in inequality would decrease average growth by slightly more than 0.1 percentage points per year. In addition to decreasing economic growth, a greater income inequality can directly affect the air travel demand as well. To be more specific, as already observed in other markets such as the cars market (Lescaroux 2010) and the energy market (Adom et al. 2021), a greater income inequality can reduce the overall demand for a certain good or service and can reduce the income elasticity. Since it is a relatively new topic within the air transport research community, the number of articles assessing the effects of income inequality on the air travel demand is rather limited (Ballard et al. 2019, Gosling & Ballard 2019). However, basing on the line of reasoning according to which a greater income inequality within a country can reduce the income elasticity, since the elasticity value found previously is slightly lower than the others found within the academic literature for the same market, it reasonable to assume that elasticity value estimated before (and that will be used to forecast air travel demand) already reflects the impact of the income inequality within the country. All these parameters are summarized in Table 1.

3.4 Estimating Airfares and the direct rebound effect

Since no direct estimation on the evolution of airfares exist, it has been necessary to define the expected evolution of crude oil prices, labour costs and aircraft efficiency in order to assess the airline ticket prices in the next 27 years. With regard to the crude oil prices, acknowledging that the price of carbon is very difficult to predict, especially at a global level given likely national or regional differences, this paper relies on the estimation of the Energy Information Administration (EIA). The EIA predicts that by 2025 Brent crude oil's nominal price will rise to $67/b (in 2021 dollars). By 2030, world demand is seen driving Brent prices to $79/b. By 2040, prices are projected to be $84/b. By then, the cheap oil sources will have been exhausted, making it more expensive to extract oil. By 2050, oil prices could be $90/b[7][8]. Then, since there exist no direct estimation of the evolution of wages and salaries in the aviation industry, a trend projection based on the last twenty years has been performed to assess the labour costs within the US aviation industry in the next three decades. With regard to the aircraft efficiency, although the historical efficiency gains in the last 30 years amounted to an average of 1% per year (Owen et al. 2010, Benzakein 2014), the aspirational goal

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[7] Since the EIA's projections provided information on the prices of crude oil only in 2025, 2030, 2040, and 2050, years in-between have been linearly interpolated.

[8] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-AEO2022&region=0-0&cases=ref2022&start=2020&end=2050&f=Q&linechart=ref2022-d011222a.3-1-AEO2022&map=&sourcekey=0

set by ICAO is a 2% improvement in the aircraft efficiency per year[9] (ICAO 2022). Although it may seem an objective difficult to achieve given the historical trend, it is worth noting that airline companies will suffer in the future more than in the past the pressure to decarbonize their activities. Therefore, further investments and research are expected to improve aircraft designs, engine efficiency, and operational activities in order to reduce the fuel consumption and the Greenhouse Gases emissions. To conclude, it has also been necessary to define whether efficiency gains can increase the overall air passenger demand, namely if there exist or not a direct rebound effect within the US aviation market. Within the academic literature, the most recent estimates identify in the US domestic aviation market an average direct rebound effect of 19% (Evans & Schäfer 2013). However, since that study was conducted on 2005 data, projecting an 18-years-old value for the next 27 years would have meant ignoring the increasing level of maturity of the US aviation market. To be more specific, as already observed in other markets in the industrialized world (Small and Van Dender, 2007, Miyoshu & Fukui 2018), over time, as income continues to grow, airfare elasticities decline, and the value of time increases, the rebound effect tends to decline and to become negligible. Therefore, no rebound effect has been taken into account in this paper. All these parameters are summarized in Table 2.

4. RESULTS, POLICY IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

After collecting the data, airfares have been projected first and then the domestic air travel demand has been forecasted. Airfares have been calculated in nominal terms before and then corrected for the expected rate of inflation (2.3%) used by the US governments for the projections[10]. The evolution of airline ticket prices reflects the trend of the last twenty years, namely nominal prices increasing and real prices decreasing.

Instead, with regard to the air travel demand projections, some interesting results emerge; first, in the time period 2023-2042, by taking into account only the real GDP and the inflation-adjusted airfares, this model forecasts a 2.35% increase per year compared to a 2.6% increase estimated by the FAA. This difference may be partially explained by the fact that the FAA assumed a 2.3% GDP growth in the next 20 years. Second, when taking into account the effects of climate change, fiscal imbalance and income inequality, the air travel demand growth decreases to 2.15% (Graph 1).

Although the small difference, this result represents a good basis to develop some reasoning in terms of policy implications. In fact, despite without an appropriate quantitative analysis it's not possible to provide any advice on a "best policy", what emerged during the literature review process and during the calibration stage still represents a good basis to develop at least some preliminary reasonings.

First, although no papers have been published yet assessing the potential impact of the physical effects of climate change on the US aviation industry, anticipating the effects of climate change on the aviation industry and protecting airports from extreme weather events is of paramount importance for the US

[9] It is important to note how these expected annual gains in efficiency exclude revolutionary changes in propulsion technology and they are additional to the general improvements in productivity captured by GDP projections.
[10] https://www.whitehouse.gov/wp-content/uploads/2023/03/ap_3_long_term_fy2024.pdf

government. By implementing robust policies, which has already partially happened with the Bipartisan Infrastructure Law[11] and the Airport Infrastructure Resilience Act[12], and investing in resilience measures, the government can ensure the safety of passengers, maintain uninterrupted operations, mitigate economic losses, and adapt to the evolving climate. Emphasizing research, innovation, international cooperation, and climate change considerations will pave the way for a resilient and sustainable aviation sector, safeguarding the nation's vital air transportation network. Therefore, further research on how to assess, contain, and prevent the effects of climate change is expected in the next few years.

Second, since an increasing fiscal imbalance and income inequality may have negative effects on the economic growth, the US governments should begin a consolidation process in order to reduce the net debt and should implement better redistribution policies in order to fill the gap between the rich and the poors within the country. In addition to this, although this topic was not addressed in the paper, climate change may have an impact on public debt and income inequality as well. To be more specific, although the effects of climate change on the fiscal imbalance and on income inequality have long been regarded as problems unique to developing countries, especially over the last few years, the academic literature has underlined how these issues, albeit obviously with different intensities, can affect both developing and developed countries (Zenios 2022, Chisadza 2023). Although these topics needs to be further investigated in the future, investing resources for a low-carbon transition in order to reduce the future impact of climate change can be beneficial not only for the aviation industry itself but for the overall economy as well.

To conclude, it is worth underlying that one implicit assumption of the model is that economic growth causes air travel demand. However, this assumption may be only partially true or even false. In fact, one of the most controversial topics within the air transport research community is the causal relationship between economic growth and air travel demand. There are countless studies using economic growth indicators (namely, employment, income, GDP and variants of them) as determinants of air travel demand and only few dissenting voices presenting evidence of bi-directional causal relationship or even a one-way relationship in which air travel stimulates economic growth. Although this paper joins that branch of the literature that assumes a uni-directional causal relationship from economic growth to air travel demand, the final results in terms of policy implications slightly changes. To be more precise, if the demand for air transportation is the real engine of economic development (and not vice versa), then the US government should pose even more attention to protecting already existing and new airports from extreme weather events.

5. CONCLUSION

As stated in the introduction, the main goal of this paper has been to test whether the Federal Aviation Administration's projections for the US domestic aviation market can be considered realistic or not. In order

[11] https://www.faa.gov/bil/airport-infrastructure#:~:text=The%20Bipartisan%20Infrastructure%20Law,transit%20connections%20and%20roadway%20projects.

[12] https://www.markey.senate.gov/news/press-releases/senator-markey-introduces-legislation-to-ensure-us-airports-are-ready-to-respond-to-climate-change-and-extreme-weather

to do so, a reduced-form economic model including GDP and airline ticket prices has been used to forecast the US domestic air travel demand from 2023 to 2050. Moreover, by including factors which are usually overlooked within the air transport research community such as the impact of climate change, the fiscal imbalance and the income inequality distribution, some interesting insights emerge. From the simple approach retained in this paper, two main results emerge: first, the domestic air travel demand in the US is not set to decline anytime soon since the GDP growth and the reduction in the (real) airline ticket prices will still represent the main driver of growth of the aviation industry; and second, the Federal Aviation Administration's projections appear to be slightly overoptimistic.

In addition, this paper also discusses the policy implications. From that analysis, several points emerge. First, investing now in a low-carbon transition is necessary to limit the effects of climate change in the future. Second, further investigating the effects of climate change on the aviation industry appears to be necessary to develop effective and efficient policies to safeguard the nation's vital air transportation network. Third, fiscal consolidation and redistribution policies should be implemented in order to minimize the potential effects that an increasing fiscal imbalance and a greater income inequality may have on the economic growth. Moreover, since the relationship between climate change and the two above-mentioned phenomena is still unclear within developed countries, this area represents an interesting field of research in the upcoming future.

Of course, because of its simplicity, the approach retained in this paper has omitted several factors which could conceivably also affect the future air travel demand. For example, unlike in the past, the US aviation market in the future may face challenges never seen before including the ever-increasing environmental awareness of consumers in the form of flight-shame movement which may lead citizens to avoid taking planes (Mkono 2020) or the introduction of high-speed trains[13] which may decrease the demand for specific routes. In addition to this, the same reasoning could be applied to the factors affecting the airline ticket prices evolution. To be more specific, it is uncertain what impact the consolidation process within the US aviation due to mergers and acquisitions, the evolution of prices and availability of sustainable aviation fuels, and the effects of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) might have on airfares.

[13] https://www.forbes.com/sites/alanohnsman/2023/05/25/the-us-is-preparing-to-put-billions-into-high-speed-rail/

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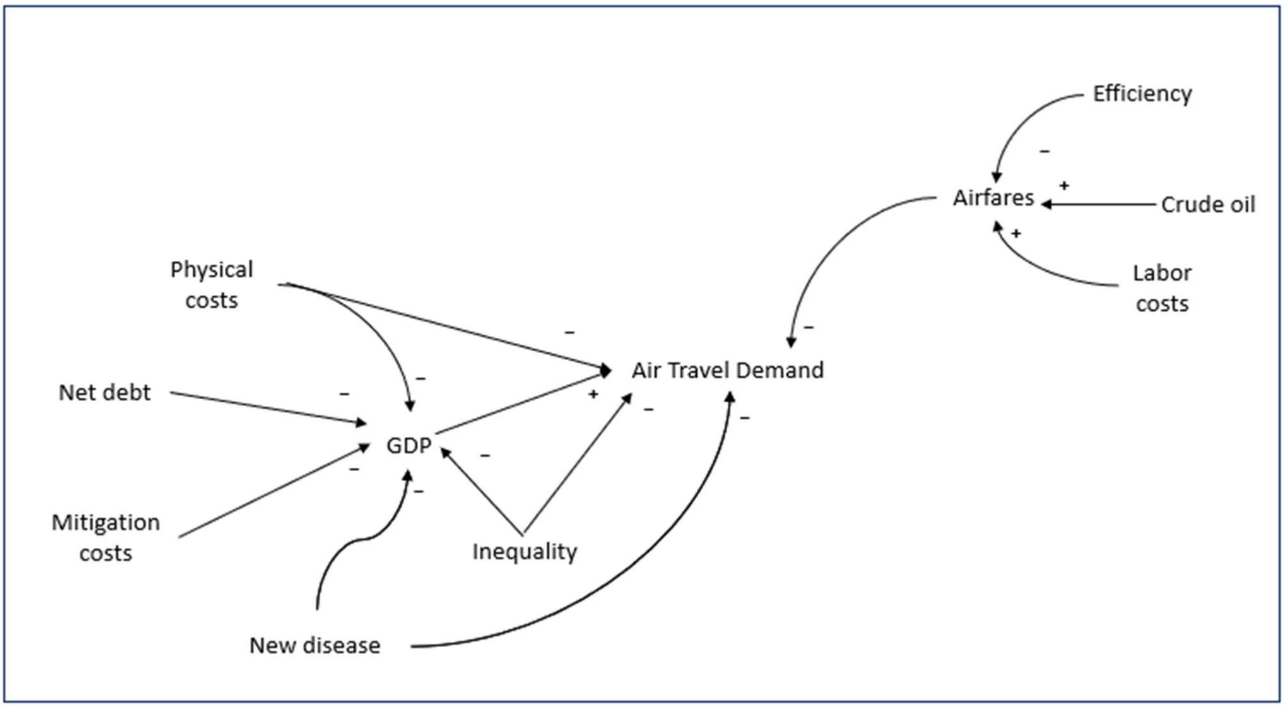
APPENDIX

FIGURE 1: Casual relationships within the model



SOURCE: Author's elaboration

TABLE 1: GDP projections and Effects of climate change, fiscal imbalance and income inequality on GDP growth

VARIABLE	2023-2032	2033-2042	2043-2050	Source
GDP	1.9	1.6	1.5	CBO (2022)
PHYSICAL COSTS	-0.033%	-0.033%	-0.033%	Hernstadt, & Dinan (2020)
MITIGATIONS COSTS	-0.023%	-0.023%	-0.023%	Williams et al. (2021)
DESEASE	Neg.	Neg.	Neg.	//
DEBT	-0.012%	-0.03%	-0.05%	Kumar & Woo (2010)
INEQUALITY	-0.12%	-0.12%	-0.12%	Cingano (2014)

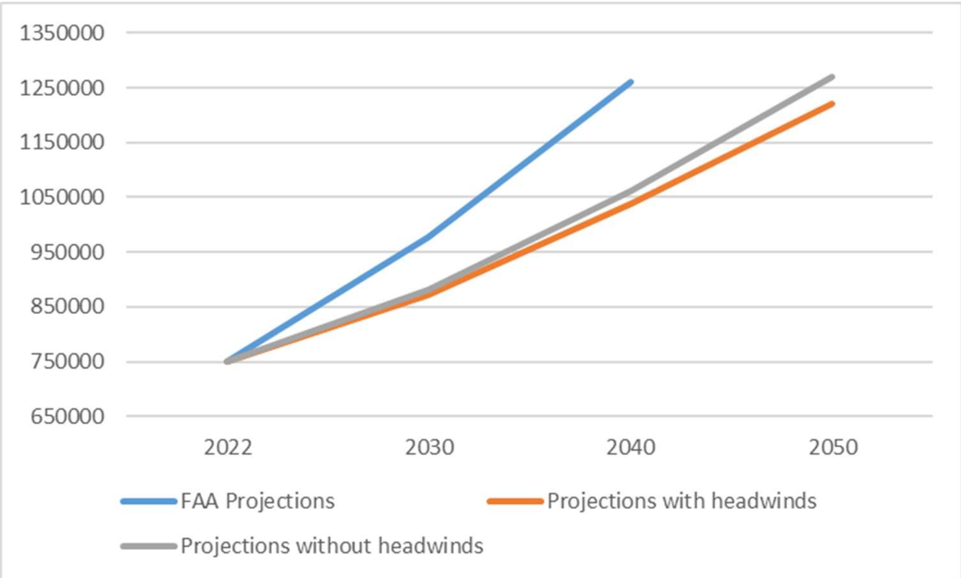
SOURCE: Author's elaboration

TABLE 2: Projected evolution of airfares' determinants

VARIABLE	2022	2030	2040	2050	Source
Crude Oil (Brent)	$98/b	$79/b	$84/b	$90/b	EEA 2022
Wages & Salaries	95'157$	111'164	131'172	151'181	Trend Projection
Aircraft efficiency	2%	2%	2%	2%	ICAO 2022

SOURCE: Author's elaboration

GRAPH 1: Air travel demand forecasts



SOURCE: Author's elaboration

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