Incorporating Air Transport Congestion into a Computable General Equilibrium Model of the US Economy

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Abstract

Air transport, like all transport sectors, has a strong relationship with national-economic performance. Consequently, investments that produce large changes in the availability of air transportation will have impacts on overall economic growth. This relationship makes an economy-wide framework relevant for evaluating the aggregate and cross-industry impacts of air transport policy and large-scale investment. One such investment is the Next Generation Air Transportation System (NextGen) initiative of the U.S. Federal Aviation Administration (FAA). In part, NextGen is intended to reduce the growth of congestion as the consumption of air transportation continues to increase in the future. Computable General Equilibrium (CGE) models describe an economy by linking supply and demand for all commodities and include macroeconomic relationships. This paper describes an interdisciplinary approach for modifying the U.S. Applied General Equilibrium (USAGE) model to reflect air transportation congestion through decreasing returns to scale (DRTS), and characterizes the consequence this modification has on modeled economy-wide NextGen impact.

1 Introduction

Air transportation both supports economic growth and is driven by it. In the United States, direct airline, airport, and air courier operations make up approximately 1.8% of gross domestic product (GDP) (FAA, 2014). The industry accounts for an even larger piece of the economy if secondary effects on manufacturing, related travelers' expenditures, and noncommercial aviation operations are included. The US Federal Aviation Administration (FAA) has embarked on a national airspace modernization effort (NextGen) anticipated to cost air carriers and the FAA a total of $39 billion (2013 dollars). This investment will benefit passengers, carriers, the FAA, and the general public. These benefits are estimated to have a net present value of $59 billion (2013 dollars) (FAA, 2013). Given the size and importance to the economy of the air transportation industry, an economy-wide assessment of NextGen that illustrates the overall effect and distribution of the costs and benefits across the economy would put industry-level analyses in a broader context and supplement standard cost-benefit analyses (CBA).

Economy-wide assessment can be carried out with a computable general equilibrium (CGE) model. Typically, partial equilibrium models contain information on supply and demand for one market while holding everything else constant. Shocks or changes to the market do not have an effect on the rest of the economy. In contrast, general equilibrium models include the entire economy with all markets (supply and demand) interacting. Shocks to one market can have consequences for other markets and the economy as a whole.

However, until computers became powerful enough to process all of the equations necessary to compute a general equilibrium model, this class of model was purely theoretical. As the models became computable, this class of models became known as Computable General Equilibrium (CGE) models. For a comprehensive explanation of these models, see Burfisher (2011) and Dixon and Jorgenson (2013).

A frequent, basic assumption of CGE models is that each industry is perfectly competitive and experiences constant returns to scale (CRTS) in the production of goods and services. This assumption reduces computational demand and is adequate for many practical applications. However, for analyses that focus on industries with significant decreasing returns to scale (DRTS) or increasing returns to scale (IRTS) in production, the CRTS assumption can distort the results. Thus, it is necessary to modify the model to compensate. For transportation-producing industries – or any other industry whose outputs are subject to capacity limitations – the CRTS assumption is likely inappropriate. This is true for air transport. The source of much of NextGen's economic benefit, as modeled by FAA, is reduction in delays due to congestion experienced by airlines and passengers. Congestion can be incorporated into the CGE framework as decreasing return to scale (DRTS), informed by national airspace operational modeling.

This paper describes a method for incorporating air transport congestion into a CGE model, in a manner suitable for a diverse, interdisciplinary audience. It is anticipated that both transportation modelers and economic modelers will find the method and results interesting. The method is then applied to an analysis of the impact of NextGen on the air transportation industries, as well as the entire economy, focusing on the reductions in congestion produced by NextGen (congestion is a subset of total NextGen benefits). The structure of the paper is as follows: Section 2 discusses the conceptual implications of non-constant returns to scale; Section 3 describes how congestion was modeled for the air transportation industry using DRTS; Section 4 defines the scenarios that are compared; Section 5 shows the effect of congestion (via DRTS) on prices and output and discusses the importance of capturing these industry-specific effects; Section 6 provides an economy-wide analysis of NextGen including the cost of implementing NextGen and the previously described congestion effects; and finally, Section 7 summarizes and discusses the contributions of this analysis.

2 Returns to Scale in a CGE Model

2.1 Overview

This section describes how congestion in air transportation is modeled in the context of a CGE model, in particular, the USAGE (US Applied General Equilibrium) model. This is a widely-used, dynamic CGE model of the U.S. economy.[1] As in all CGE models, optimizing behavior governs decision-making by

[1] USAGE was developed at the Centre of Policy Studies (formerly at Monash University and now at Victoria University, Melbourne, Australia) in collaboration with the U.S. International Trade Commission. Its theoretical structure is similar to that of Australia's MONASH model (Dixon and Rimmer, 2002). Recent published applications of USAGE include Dixon and Rimmer (2011), Dixon *et al.* (2013) and Zahniser *et al.* (2012).

firms and households. In general, industries are perfectly competitive and minimize costs subject to constant-returns-to-scale production functions and input prices that they treat as given. Households also take prices as given and choose their consumption bundle to maximize utility subject to their budget constraint. Domestic and imported goods are treated as imperfect substitutes. Explicit recognition is given to tax, transport and other margins that separate purchasers' prices from producers' prices. Because the industries are perfectly competitive, any improvement in a production function that causes goods or services to be cheaper to produce will ultimately benefit consumers via lower prices, all else constant.

For this application, USAGE has been modified to handle DRTS for the air transport industry. This version of the model is referred to as USAGE-Air, as it was developed by modifying the USAGE model to emphasize industries related to air transportation and accommodate congestion-related DRTS in air transportation.

2.2 Implementing Decreasing Returns to Scale

Conceptually, CRTS, DRTS, and IRTS are features of production technology, and can be understood through simple illustrations relating inputs and outputs. In the case of CRTS, twice the inputs are required to double output, given a production technology. In a DRTS industry, more than double the inputs are required to double the output, and in an IRTS industry, fewer than double the inputs are required. Consequently, with DRTS, as production increases, the unit-cost of production also increases; with IRTS, it is the opposite; with CRTS, unit-cost of production is invariant to the amount being produced.

If changes in congestion are ignored, as more flights are added to the airspace, average delay per flight is unaffected. However, more realistically, when changes in congestion are considered, as more flights are added, each flight experiences increasing delay. Thus each additional unit of transportation produced requires more inputs of labor and capital and intermediate inputs (such as fuel) than previous units. Conceptually, congestion can be viewed as a technological deterioration which causes DRTS in production of air transportation.

What follows is a notional example to illustrate how DRTS (and likewise, IRTS) is implemented. Imagine an economy with a single industry. To illustrate the macroeconomic effects of DRTS in a very simple way, consider this economy where output Y is a function of capital (K), labor (L) and technology (A) as represented by equation 1. H is an increasing function of both K and L; the technology variable, A, simply scales the level of output to the production function.

$$Y = A \cdot H(K, L) \tag{1}$$

In this context, the basic effect of DRTS is a feedback of output level to the technology variable. With DRTS, the feedback is negative and with IRTS the feedback is positive.

The basic USAGE model uses production functions with CRTS of the form in Equation 2.

$$X0(j,t) = G_j\left(\frac{X1(1,j,t)}{A1(1,j,t)}, \frac{X1(2,j,t)}{A1(2,j,t)}, \dots, \frac{X1(n,j,t)}{A1(n,j,t)}\right) \ \forall\, j \in J \quad (2)$$

where,
$X0(j,t)$ is the output of industry j at time t;
G_j is a CRTS function;
$X1(i,j,t)$ is the use of input i (intermediate inputs, labor and capital) by industry j at time t;
$A1(i,j,t)$ is a variable allowing for input-i-saving technical change in industry j at time t; and
J is the set of all industries in the USAGE-Air model.

The A1 terms in the denominators of Equation 2 are technology variables. These variables control the quantity of inputs which are required to produce a unit of output. In the static CRTS model, these variables are constant (and the time variable is irrelevant). In a dynamic model, these variables can change over time, altering the production function.

It is these variables which allow the modeling of congestion-related DRTS in USAGE-Air. More specifically, changes to the aviation system are modeled as technology shocks to the air transportation industries in the form of technology variables (A1) which are functions of the output of those industries.

For the purpose of describing DRTS modeling in USAGE-Air, a generic technological change in air transportation at time t is defined in Equation 3.

$$\mathrm{A1}'(\mathrm{i,j,t}) = \mathrm{A1}(\mathrm{i,j,t}) \cdot \mathrm{F}(\lambda_t, \dots) \quad (3)$$

Here, $\mathrm{A1}(\mathrm{i,j},t)$ is the original technical change variable from Equation 2. The function F(.) is the factor by which inputs (including fuel, labor, and others) need to increase to produce a unit of air transportation, given DRTS. The function $\mathrm{F}(\lambda_t, \dots)$ depends on the number of flights flown, represented by λ_t. $\mathrm{F}(\lambda_t, \dots)$ also depends on other variables related to the characteristics of the aviation system. These additional variables are used to parameterize the effect of NextGen and are described in Section 3. Thus, equation 2 is rewritten as equation 2´ for the air transportation industries,

$$X0(j,t) = G_j\left(\frac{X1(1,j,t)}{A1'(1,j,t)}, \frac{X1(2,j,t)}{A1'(2,j,t)}, \dots, \frac{X1(n,j,t)}{A1'(n,j,t)}\right) \forall\, j \in AT \quad (2')$$

where A1´ is from Equation 3 and AT is the set of air transportation industries and $AT \subset J$.

In USAGE-Air, there are two air transportation industries – domestic air transportation and international air transportation. These are separated because they are inherently different goods that are not directly substitutable and because they experience different degrees of DRTS, as explained later.

3 Connecting Congestion and DRTS in USAGE

3.1 Roadmap for Modeling Congestion and Connecting it to USAGE-Air

Section 2 outlines the general mechanism for incorporating DRTS into the USAGE-Air model. In the case of the air transportation industries, the technological deterioration that leads to DRTS is modeled as coming from congestion in the U.S. National Airspace System (NAS). As more air transportation is produced, congestion increases and the resources needed to produce a unit of air transportation also increases.

This section of the paper describes how congestion modeled by the FAA can be approximated by a relatively simple queuing model and how this queuing model can be integrated into the USAGE-Air CGE model. This involves translating the output of the air transportation industries as viewed by the air traffic control system (i.e., flights) to the output of those industries in economic terms. The relationship between flights and economic output is dynamic through time as the properties of the air transportation industries change (for example, if future aircraft are expected to be larger, on average, than current aircraft). By accounting for these factors, an accurate translation from flights to economic output can be achieved.

3.2 Mechanics of Modeling Delay

Modeling congestion and delay in the NAS receives considerable attention from the FAA and requires highly sophisticated expertise and specialized computational tools (Shresta, 2014). However, Kamble (2005) reports that a simple queuing function can used to fit operational delay data to traffic levels. Here, a similar approach is used to generate a fit of system-level delay to traffic level based on a system-level simulation.

A functional form for delay (d_s) similar to queuing time in a simple M/M/1 system[2] was chosen. The addition of a scaling parameter (s) is to better match the observed dependence of system-level delay on traffic level observed. The delay function is shown in Equations 4 and 5,

$$\mathrm{d_s}(\mathrm{t}) = \max\left\{0, \mathrm{c_s}\left(\frac{1}{\bar{\lambda}_t - \lambda'_t} - \frac{1}{\bar{\lambda}_t}\right)\right\} \tag{4}$$

$$\lambda'_t = \frac{\lambda_t - \mathrm{s}_t \cdot \bar{\lambda}_t}{1 - \mathrm{s}_t} \tag{5}$$

where,

$d_s(t)$ is the delay per flight (in seconds) in the year t;

$\bar{\lambda}_t$ is the theoretical maximum system traffic (in flights) in year t;

λ_t is a measure of system traffic (flights per day) where $\lambda_t < \bar{\lambda}_t$; and

c_s and s_t are parameters with $c_s > 0$ and $0 \le s_t < 1$.

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[2] The M/M/1 queuing system is a very simple queuing model. It calculates the queue length in a system with a single server. The first "M" indicates that arrivals are Markovian (random). The second "M" indicates that the service time is Markovian with an exponential service time. The "1" indicates that there is a single service channel, or server. For a full description of queuing theory, see Gross, et al. (2008).

Based on this functional form, there is no delay when $\lambda_t < s_t \cdot \bar{\lambda}_t$. As λ_τ approaches $\bar{\lambda}_t$, delay increases rapidly. Recall that the scaling parameter, s_t, is implemented so that delay does not become non-zero until traffic levels exceed a certain threshold. A notional example of this functional form is shown in Figure 1.

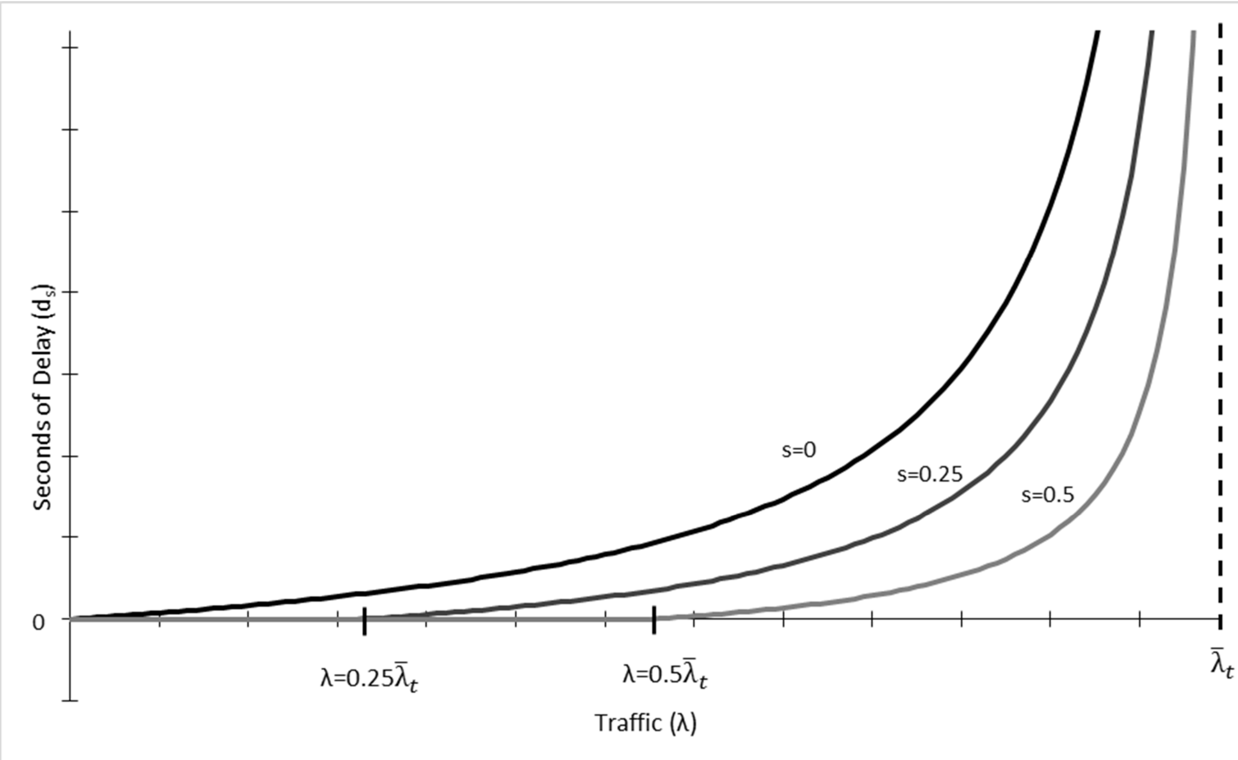

Figure 1: Delay as a function of traffic level and the scaling parameter

The motivation for using this functional form is to produce inputs for USAGE-Air (which models entire industries on an annualized basis) from a highly atomized model of aviation congestion. The FAA's model, System-Wide Analysis Capability (SWAC), is very complex and simulates the operations of thousands of individual flights using many capacity-limited resources, such as airports and airspace. The performance of these flights, as a function of overall traffic level, is determined through a sophisticated estimation process that provides a level of detail unnecessary for USAGE-Air.

To produce inputs for USAGE-Air, the behavior of thousands of individual flights in SWAC must be generalized. At this aggregate, system-wide level, SWAC simulations indicate that as traffic levels increase, delay increases at an increasing rate. At sufficiently high traffic levels, modeled delays become so large that they would not be observed in reality (e.g., no flight would operate if the average delay per flight was 40 hours). This relationship between modeled traffic and the corresponding level of congestion is very typical of a queuing system with finite capacity (i.e., Equations 4 and 5).

3.3 Fitting SWAC Model Output to the Delay Function

Given the functional form described in Equations 4 and 5, the next step is to estimate the parameters of those equations that best describe the output from SWAC simulations. Using SWAC, average delay (in seconds) per commercial flight was simulated for different traffic levels (i.e., total aggregate number of flights). Additionally, NAS system-wide capacities for the years 2011, 2015, 2020, 2025, and 2030 were used. By combining the different traffic levels and capacities, delay was estimated across a wide range of system capacities and traffic.

To fit SWAC outputs to Equations 4 and 5, the set of parameters (s_t, c_s , and $\bar{\lambda}_t$) that minimizes the root-mean-square error is estimated. Examining future forecasts of air traffic reveals that the relevant demand levels for commercial flights between 2011 and 2030 ranges between roughly 30,000 and 50,000 flights per day. Thus, curve fits were produced using observations from SWAC that fall in that range. An example of this fit is shown in Figure 2 which shows how delay varies when traffic levels change and the capacity of all system resources is kept fixed at the capacity levels from 2011.

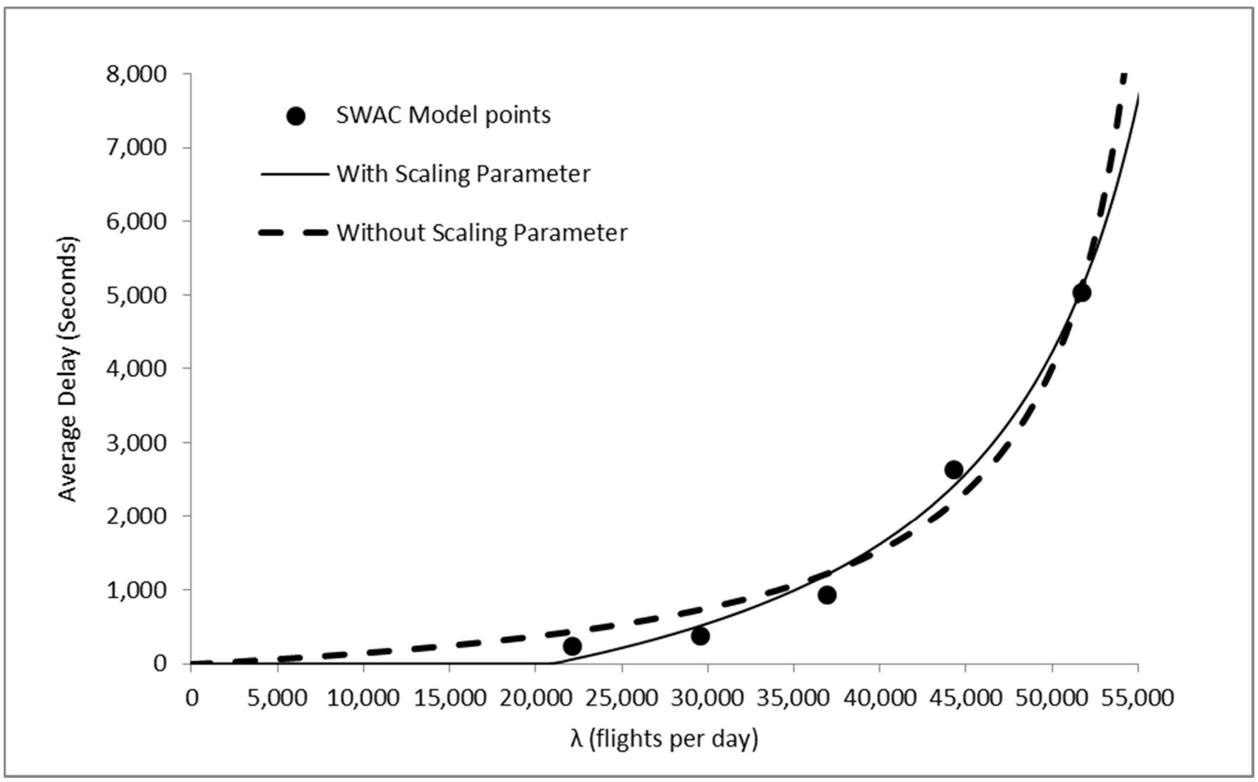

Figure 2: Average Delay per Flight as Modeled in SWAC Using 2011 Capacity

Figure 2 illustrates two important characteristics of the functional form for aggregate delay measures. First, the addition of a scaling parameter allows for a better (and more realistic) relationship between traffic level and delay. The scaling parameter allows delay to remain at zero up to a certain number of flights, which is consistent with observed delay.

Second is that using the scaling parameter minimizes the difference relative to the SWAC simulations by estimating values for s_t, c_s , and $\bar{\lambda}_t$ at various levels of λ_t. The parameter, $\bar{\lambda}_t$, is the estimated theoretical maximum number of flights per day; s_t, along with $\bar{\lambda}_t$ defines the traffic level at which delay begins to occur; and c_s is essentially a free parameter that is used to calibrate the M/M/1 equation to the scale of the SWAC output. The resulting minimization identifies the parameters that best describe the delay function and allow an estimated delay to be generated for any given traffic level.

3.4 Translating Estimated Delay to Cost of Delay

By estimating the delay function described in the previous sections, the expected average delay per flight at any level of traffic can be calculated. However, recall that the output of the aviation producing industries in USAGE-Air is measured in dollars. Thus, it is necessary to convert seconds of delay per flight into dollars of cost to air carriers.

The cost of delay is measured in dollars per second of delay. For the purposes of this paper, it was estimated to be $0.63 per second (FAA, 2007). This figure is a weighted average of at-gate, on-ground (but not at-gate), and in-flight delay and is consistent with, if more conservative than, other research in this area (Airlines for America, 2014). In the previous section, the seconds of delay per flight was estimated. To estimate the total yearly cost of delay, all that is needed is the number of flights in that year. Thus, the total cost of delay in year t, is

$$CD(t) = c_d * d_s(t) * \lambda(t) \tag{6}$$

where,
CD(t) is the total cost of delay in year t,
c_d is the cost of delay per second,
d_s is the delay (in seconds) per flight in year t, calculated from Equations 4 and 5, and
λ(t) is the total number of flights in year t (i.e., λ_t*365).

As a note, the distinction between λ(t) and λ_t is that λ(t) is the *yearly* count of flights where λ_t is the daily count for each day in year t. This translation is necessary because SWAC estimates daily traffic levels and capacities whereas USAGE-Air estimates yearly outputs of the air transportation industries.

3.5 Relating Flights to Economic Output of the Aviation Industries

From USAGE-Air, dollar measures of output (X0) from industries that produce air transportation can be extracted. The total real value (i.e., where prices remain constant through time) of air transportation in the US is,

$$X0(t) = \sum_{j \in AT} \mathrm{X0(j,t)} \tag{7}$$

where the summation is across air transportation-producing industries, j.

To integrate the model of congestion with the economic model, the number of flights, $\lambda(t)$, which drives congestion costs through equation 6 must be related to the real value of output, X0(t), which is driven by demand for air transport services. To start this process, X0(t) is written as a function of the output of air transportation (revenue passenger miles, or RPM) and the price of RPMs in the base year, t_0. This relationship is shown in Equation 8.

$$X0(t) = RPM(t) * P_{RPM}(t_0) \tag{8}$$

where X0(t) is the real value of air transportation output in year t;
RPM(t) is the revenue passenger miles produced in year t;
and $P_{RPM}(t_0)$ is the price of a revenue passenger mile in the base year, t_0.

RPM(t) is related to number of flights by

$$RPM(t) = \lambda(t)RPMPF(t) \tag{9}$$

where RPMPF(t) is revenue passenger miles per flight in year t.

Via the variable RPMPF(t), changes in gauge (the size of airplanes) and load factor (how full each plane is) are introduced. Both gauge and load factor have changed historically and are forecasted by the FAA to change in the future. Flight length is another important feature of RPMPF that is held constant in this analysis that should be considered in future work. The FAA forecast (2012a) includes very little change in average flight length in the first ten years out, and a mild upward after that. For this study, increases in RPMPF mean bigger, fuller flights.

Using historical and forecast data from the FAA (2012a), Figure 3 plots normalized revenue passenger miles per flight (RPMPFN) as a function of year (normalized to 2010 levels) and RPMPFN as a function of RPMs for scheduled passenger traffic. By year, RPMPFN has increased fairly steadily (shown in the left-hand graph). In contrast, as a function of total RPMs, RPMPFN has historically shown a non-linear behavior (below RPM values of about 800 billion per year). Regardless, in the FAA's forecast (i.e., RPM greater than about 800 billion per year) RPMPFN increases smoothly with increasing RPM.

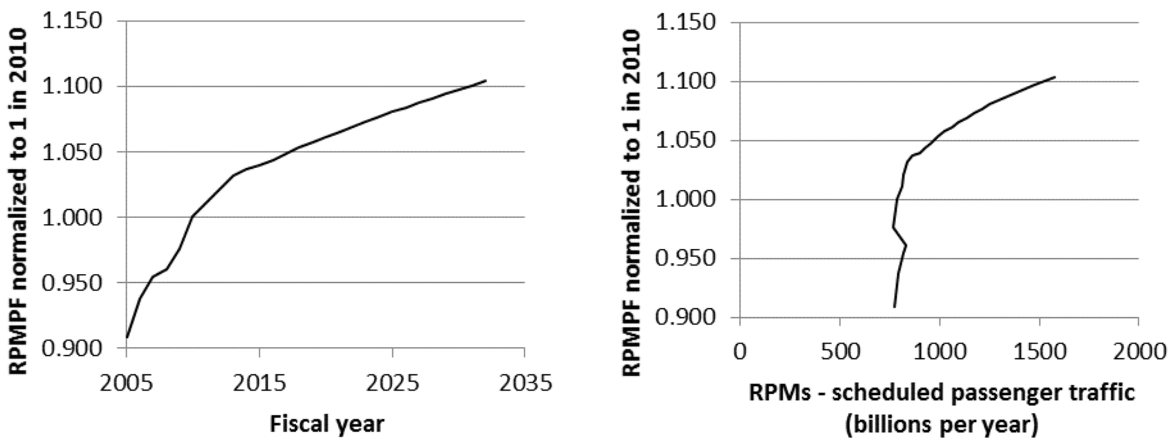

Figure 3. RPMPFN as a Function of Year and as a Function of Annual RPMs

Figure 4 shows a fit of RPMPFN to annual RPMs such that the value of RPMPFN is exact in 2010 and at the FAA's value at the maximum forecasted value of RPMs. This fit shows that, on average, for every 1% change in RPMs, RPMPFN changes by 0.142%. This fit is used in the modeling reported in this paper to represent future changes in average aircraft gauge and load factor. While longer flights are also a potential source of increases in RPMPFN, FAA forecasts of average stage lengths move little through 2020 (FAA 2012a). A treatment including stage length with aircraft gauge and load factor is an area for future work.

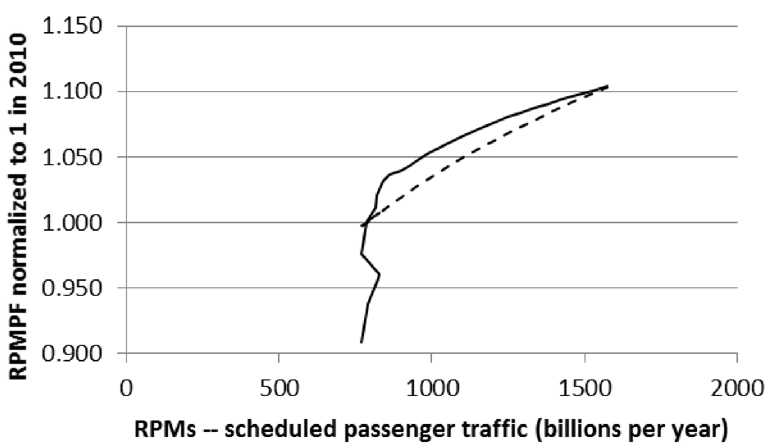

Figure 4. Fitted (Dashed Line) RPMPFN as a Function of Annual RPMs

Equation 10 shows the relationship between RPM and RPMPFN as fitted in Figure 4.

$$RPMPFN(t) = \frac{RPMPF(t)}{RPMPF(t_0)} = \left[\frac{RPM(t)}{RPM(t_0)}\right]^a = \left[\frac{X0(t)}{X0(t_0)}\right]^a \qquad (10)$$

where the parameter, a, measures the percentage by which RPMPFN changes when RPM changes by 1%; and RPMPFN(t) is the normalized RPMPF in year t (i.e., the ratio of RPMPF(t) to RPMPF(t_0)).

Combining Equations 8, 9 and 10 yields Equation 11 which gives the required relationship between the number of flights in a year and economic output.

$$\frac{\lambda(t)}{\lambda(t_0)} = \left[\frac{X0(t)}{X0(t_0)}\right]^{1-a} \quad (11)$$

3.6 Integrating the Cost of Delay into USAGE-Air

Recall from Section 2.2 and Equation 3, that DRTS in the air transportation industries is implemented through the introduction of a function, F(.) which alters the technology variable. The function F(.) is the factor by which inputs (including fuel, labor, and others) need to increase to produce a unit of air transportation, given DRTS.

The function, F(.) is defined in Equation 12

$$\mathrm{F}(\lambda_t) = 1 + \frac{CD(t)}{X0(t)} \quad (12)$$

where all variables are as defined previously. Changes in annual demand for air transport drive annual flights, λ(t), via equation 11. Annual flights determine daily flights, λ_t, which feeds into equations 4 and 5 to give delay per flight, $d_s(t)$. Now there is enough information to determine congestion costs in equation 6, CD(t). From here F(.) can be evaluated via equation 12.

In effect, Equation 12 is combined with Equation 3 which is used by USAGE-Air to help determine the equilibrium output of the aviation producing industries in the context of the entire economy. From this, the equilibrium value of λ_t is acquired and the equilibrium state of the air transportation industries, while accounting for DRTS, can be determined.

4 The Three Analysis Cases

This section defines three scenarios that help illustrate the consequences of accounting for congestion-related DRTS and the benefits of NextGen. The scenarios are: the “unlimited capacity” case (CRTS), the “do-nothing” case (DRTS), and the NextGen case (DRTS with additional capacity). The difference between unlimited capacity CRTS and do-nothing DRTS will illustrate the importance of accounting for air transport congestion in the model. The difference between do-nothing DRTS and NextGen DRTS will represent the benefit of the NextGen capacity gains.

The “unlimited capacity” case is the equivalent of CRTS. As the USAGE-Air model steps through time, capacity is made endogenous to the model while delays are held fixed. As a result, the amount of additional capacity that is needed to ensure CRTS is calculated and added to the model. In essence, the technology deterioration in the variable A1´ (from equation 3) is avoided by endogenously increasing capacity in USAGE-Air by whatever amount is needed to maintain a constant value of A1´. While this case is intentionally over-optimistic, it illustrates why it is important to account for DRTS.

Further, FAA's forecasts of future air traffic are "considered unconstrained in that they assume there will be sufficient infrastructure to handle the projected levels of activity" (FAA 2012a). As this is consistent with CRTS, the model was calibrated to match FAA's aggregate forecasts (2012a) for the CRTS model runs. The differences in modeled air transportation industry activity levels between CRTS and DRTS represent a reduction in air traffic relative to the "unconstrained" forecast, driven by the incremental rising costs associated with congestion.

In the "do-nothing" case, no changes are made to the system through time[3]. As traffic levels increase and capacity remains the same, a technological deterioration occurs, of the nature discussed in Section 3. This results in DRTS.

For the NextGen scenario, each year the capacity in the system increases by an amount consistent with the FAA's NextGen Implementation Plan (NIP) (FAA, 2012b). These capacity increases result in DRTS as the total capacity is far less than in the "unlimited capacity" case. However, the DRTS experienced under NextGen are less severe than those under the do-nothing case.

Figure 5 shows a comparison of the system capacities (measured in possible flights per day) of these three scenarios. Of note is how large the capacity increases would need to be to ensure an operating environment consistent with CRTS, meaning one with no increase in average delay.

[3] This is a simplification. For an accurate analysis of the benefits of NextGen, the proper baseline is needed. When NextGen is not implemented, runway improvements that are already planned and underway will still add a small amount of capacity to the NAS. Without accounting for this increase, the benefits of NextGen would be overstated. However, for simplicity, this scenario can be thought of as the "do-nothing" case relative to NextGen implementation.

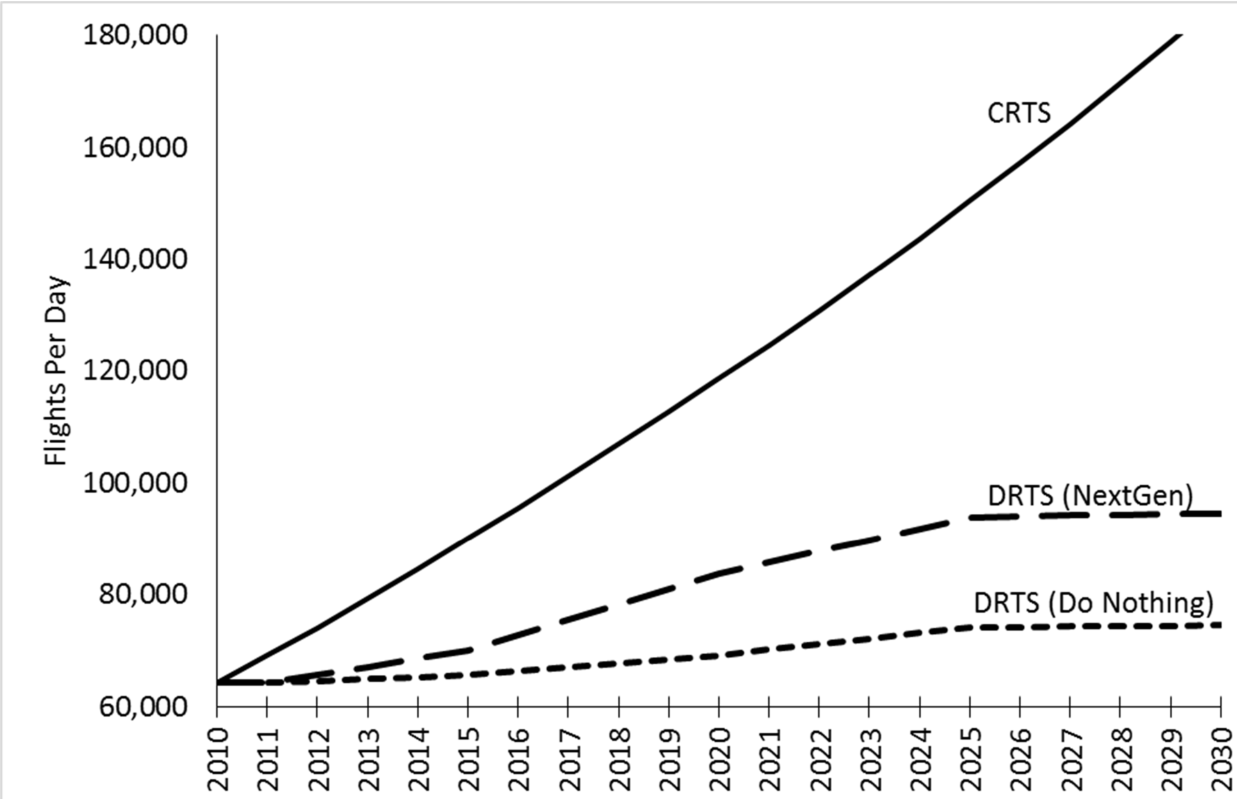

Figure 5: System Capacities Under CRTS, Do-nothing, and NextGen

5 The Importance of DRTS

In this section, an analysis of the air transportation industries is performed comparing CRTS and DRTS, illustrated primarily through prices and output. Figure 6 shows the simulated forecast of the price index of aviation from the USAGE-Air model under CRTS and the DRTS do-nothing case. It also shows the forecast of the consumer price index (CPI[4]) from the U.S. Bureau of Labor Statistics as a point of comparison. The CRTS scenario illustrates the natural rise in fares associated with general price increases across the country.

Fuel is the single largest intermediate input to the air transportation industries and assumptions about the price increase of fuel drive the shape of the simulated price index forecast. In USAGE-Air, the price of fuel is forecasted to rise in the first few forecast years, then grow steadily at a rate slightly below the CPI. Because of this, the associated price of aviation rises faster than CPI before slowly returning back.

The DRTS scenario has identical assumptions about fuel price as the CRTS scenario. However, as time passes and the number of flights and the associated congestion increase, operating costs in the air

[4] Bureau of Labor Statistics, Consumer Price Index - Chained Consumer Price Index, Series SUUR0000SA0.

transportation industry rise and put additional upward pressure on the price of air transportation. This results in prices approximately 5 percent higher in 2030 than would be expected with CRTS.[5]

USAGE incorporates forecasts from a variety of sources. All forecasts are imperfect in practice, especially considering a long time horizon such as 2030. While this may introduce a lot of uncertainty in the interpretation of the absolute levels of the prices, it is the *difference* between the price levels that is of primary interest. While historically, airfares fell in real terms for decades after deregulation, recent history has seen a reversal in this trend. Further, the real decreases in fares have been generated by competition and innovation in the air transport industry, which this study does not attempt to predict for the future. This is an area of future potential expansion for the work.

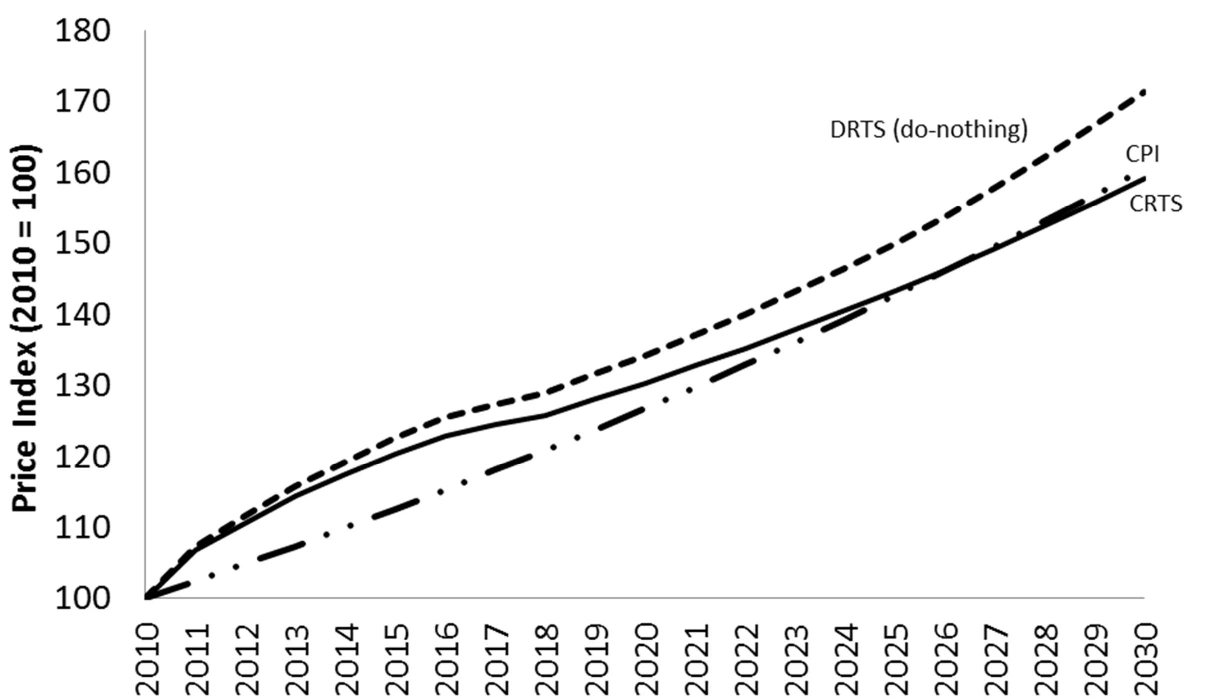

Figure 6. Increase in Consumer Price Index and Price of Air Transport with CRTS and DRTS

The introduction of DRTS, also affects industry output levels. The overall impact of DRTS on the combined output of domestic air transport and international air transport produced by US flag carriers is shown in Table 1. The unit of measurement for industry output presented here is billions of constant 2011 dollars, which exclude the movement in prices in subsequent years. The series can be interpreted as a quantity output measurement consistent with the number of revenue passenger miles (RPM) that could be bought for a dollar in 2011. While the difference in any given year appears small, the present

[5] Note that all of the scenarios in this paper assume perfect competition—meaning prices are driven to long run average costs. This is an assumption that at the national, aggregate level performs well for the industry over the decades since deregulation. The recent experience of consolidation in the industry does, however, call for future investigation into the sensitivity of results to imperfect competition.

discounted[6] value (PDV) of the cumulative difference between 2011 and 2030 is $21.7 billion. Making the assumption of CRTS in air transportation significantly overestimates the industry output.

Table 1: Output of Air Transportation Industries Under CRTS, DRTS (do-nothing) in Billions of Constant 2011 Dollars (numbers may not add due to rounding error)

	Air Transportation Output			
Year	CRTS	DRTS (do-nothing)	Difference	Difference (PDV)
2011	155.9	155.8	0.2	0.2
2012	162.1	161.8	0.3	0.3
2013	168.6	168.1	0.5	0.5
2014	175.3	174.7	0.7	0.6
2015	182.4	181.5	0.9	0.7
2016	189.7	188.7	1.0	0.8
2017	197.3	196.1	1.2	0.8
2018	204.9	203.6	1.4	0.9
2019	212.9	211.3	1.6	1.0
2020	221.1	219.4	1.8	1.0
2021	229.7	227.7	2.0	1.1
2022	238.7	236.4	2.3	1.2
2023	248.0	245.3	2.6	1.2
2024	257.6	254.7	2.9	1.3
2025	267.7	264.4	3.3	1.4
2026	278.2	274.3	3.9	1.5
2027	289.1	284.6	4.5	1.6
2028	300.4	295.3	5.1	1.7
2029	312.2	306.4	5.9	1.9
2030	324.5	317.9	6.7	2.0
Total	4,616.5	4,567.8	48.6	21.7

Table 1 shows that DRTS matters in the context of air transportation. With the assumption of CRTS, forecasted prices and output are significantly different than under the more accurate DRTS assumption. Further, by not accounting for congestion created by additional flights, an unreasonable amount of capacity improvements are implicitly assumed. As actual capacity improvements are known in advance, and congestion models are mature, it is appropriate to model DRTS in air transportation when modeling its impact on the broader economy in the context of a CGE model.

[6] A discount rate of 7% per year was used, consistent with OMB's guidance on public investment in Circular A-94 (OMB, 1992)

6 Impact of NextGen

6.1 Discussion of Costs

Properly modeling the nature of the air transportation industries inside an economy-wide CGE model, as described in this paper, allows the measurement of the impact of technology improvements in those industries. As a result, the effect on other industries and the broader economy can also be measured. Because CRTS is unreasonably optimistic and does not include congestion, the appropriate comparison is between the do-nothing and the NextGen cases. In addition to higher levels of NAS capacity than the do-nothing scenario, the NextGen scenario also includes the costs of the NextGen investment.

The cost scenario assumes the federal government raises additional taxes to cover FAA's expenditures in the year they are made and that air carriers would borrow[7] to cover their expenditures. The $37.6 billion (2011 dollars) cost of NextGen assumed in this study is nearly evenly split between the government and air carriers (FAA, 2013), though the government's expenses are more front-loaded, as shown in Table 2.

[7] Borrowing arrangements for air carriers are diverse, and there is no expectation that all carriers would borrow rather than use cash on hand. A 7% interest-only scheme was assumed to represent bounds of a permissive borrowing scheme.

Table 2: Cost of NextGen to FAA and Air Carriers in Millions of Dollars (numbers may not add due to rounding)

	Constant Dollars (2011)		PDV	
	FAA Cost	Carrier Cost	FAA Cost	Carrier Cost
2010	893	0	893	0
2011	906	143	906	143
2012	935	144	935	144
2013	901	345	842	322
2014	1,061	1,066	927	931
2015	1,363	1,239	1113	1011
2016	1,456	1,253	1111	956
2017	1,548	1,216	1104	867
2018	1,524	1,237	1016	824
2019	1,096	1,201	683	748
2020	629	1,221	366	711
2021	627	1,073	341	584
2022	632	1,122	321	570
2023	636	1,181	302	561
2024	639	1,163	284	516
2025	643	1,078	267	447
2026	647	1,103	251	428
2027	651	799	236	290
2028	654	741	222	251
2029	658	763	208	242
2030	661	737	196	218
Total	18,760	18,825	12,521	10,764

6.2 NextGen's Effect on Air Transportation

As in Section 5, the comparison between DRTS do-nothing and DRTS NextGen starts with the difference in price levels. Figure 7 shows that by 2030, the forecasted price level for air transportation would be approximately 2 percent higher without NextGen than with it. The productivity gains associated with improvements in capacity reduce costs, which reduce prices.

The industry output of air transportation is similarly affected. Table 3 shows the yearly differences, that, cumulatively by 2030, are an additional $9.9 billion PDV of production facilitated by NextGen. NextGen lowers the price level of air transportation and allows for a significant amount of additional output to be produced. While output under NextGen does not reach the same levels as under CRTS, the system clearly accommodates more air travel than the DRTS do-nothing case.

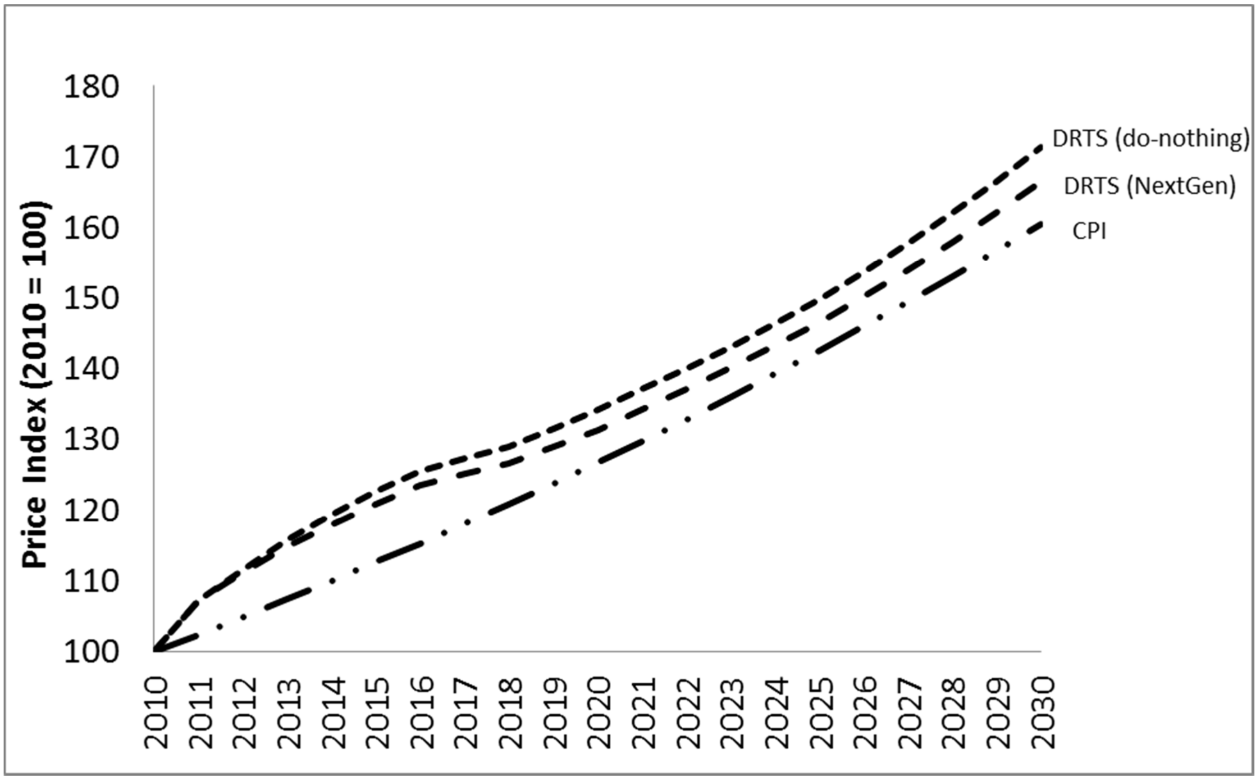

Figure 7. Increase in Consumer Price Index and Price of Air Transport (NextGen vs. Do-nothing)

Table 3: Output of Air Transportation Industries Under DRTS (do-nothing) and DRTS (NextGen) in Billions of Constant 2011 Dollars

	Air Transportation Output			
Year	DRTS (NextGen)	DRTS (do-nothing)	Difference	Difference (PDV)
2011	155.8	155.8	0.0	0.0
2012	162.0	161.8	0.1	0.1
2013	168.4	168.1	0.3	0.3
2014	175.1	174.7	0.5	0.4
2015	182.2	181.5	0.7	0.5
2016	189.4	188.7	0.7	0.5
2017	196.9	196.1	0.8	0.6
2018	204.4	203.6	0.9	0.6
2019	212.3	211.3	1.0	0.6
2020	220.4	219.4	1.1	0.6
2021	228.8	227.7	1.1	0.6
2022	237.4	236.4	1.1	0.6
2023	246.5	245.3	1.1	0.5
2024	255.9	254.7	1.2	0.5
2025	265.6	264.4	1.3	0.5
2026	275.7	274.3	1.4	0.5
2027	286.2	284.6	1.5	0.6
2028	297.0	295.3	1.7	0.6
2029	308.3	306.4	1.9	0.6
2030	320.0	317.9	2.1	0.6
Total	4,588.2	4,567.8	20.4	9.9

6.3 NextGen's Effect on Other Industries

Perhaps the most interesting use of the USAGE-Air model (or any CGE model) is to examine the secondary impacts of a program or policy such as NextGen. NextGen having an effect on the output of the aviation industry is not surprising, though learning the magnitude of the impact is informative. In considering the entire economy, the model captures the effects of the aviation industry supporting (through lower cargo and passenger fares) and stimulating (through growth in vacation-related industries) other parts of the economy. For many industries, the impact of NextGen is negligible. For instance, NextGen has nearly no impact on the utilities industry because aviation has little direct or indirect impact on the burning of coal, hydroelectric dams, water reservoirs, or any of their related infrastructure. Additionally, air transportation is not a substitute or complement to utilities.

For the industries that are impacted, the effect can be identified by examining the changes in their gross output. Figure 8 shows the industries that experience the largest increase in gross output in 2030 because of NextGen (though the pattern for any given year is very similar). The bars of the chart measure increased output in dollars, while the dots represent increased output as a percentage of total output. These differ because, while the monetary effect is large in some industries, that monetary effect is quite small compared to the size of the industry. Similarly, some industries experience a somewhat small monetary impact that is rather large in the context of the industry's size.

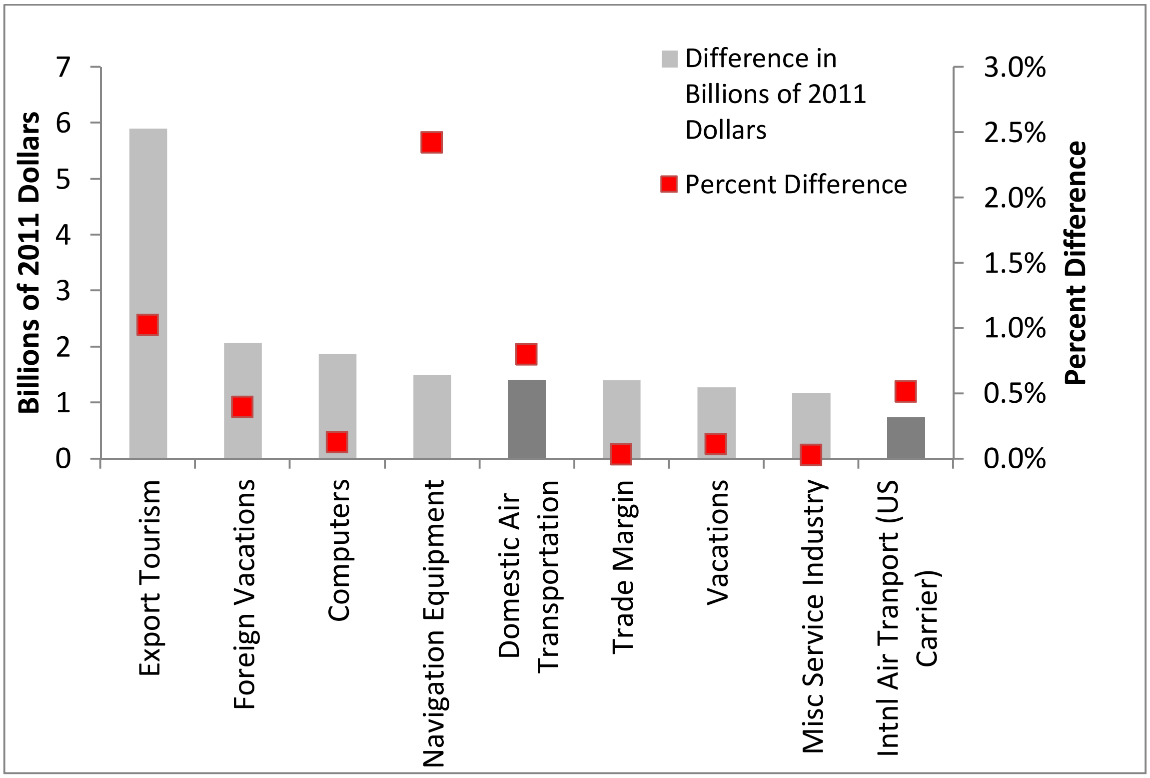

Figure 8. Industries that Benefit from Improved Air Transportation (as measured by output with and without NextGen)

The highest positive percent difference is for Navigation Equipment, which is an industry that contains all of the avionics and systems required for NextGen. As expected, industries that are very closely tied to aviation, such as export tourism (foreigners traveling to the United States for business or pleasure), vacations (U.S. residents vacationing in the U.S.), and foreign vacations (U.S. residents vacationing abroad), are also among the most positively affected industries. Vacations do not rise by the same percentage as air transport because not all air transport is consumed for vacations.

Three other effects explain the industries in Figure 8. First, an industry such as computers moves much of its output using aviation. These commodities are generally light-weight, high-value, and can often be time sensitive—the type of good that is shipped by air. Second, industries such as miscellaneous services produce the type of goods and services that consumers use when vacationing. Computers also experiences an increase in output because computers and related equipment are commonly purchased by foreign tourists. Third, the trade margin industry captures wholesale and retail services. As more goods are bought and sold, there is a corresponding increase in wholesale and retail services.

Looking instead to the industries that grow more slowly with NextGen than without, Figure 9 shows that the list is dominated by transportation industries that would do better in the absence of NextGen. In contrast to Figure 8, Figure 9 shows the industries with the largest decrease in gross output in 2030 (though the pattern for any given year is very similar). It is important to consider that these industries *do not shrink* as a result of NextGen. Rather, they grow slightly less with NextGen because they benefit from congestion in air transportation, which NextGen helps alleviate.

The industry that is affected the most (in dollars) by NextGen is trucking. Trucking is the closest substitute for aviation for shipping purposes. In the absence of NextGen, trucking benefits by selling services to people and industries that are pushed out of the air transport market by rising fares associated with congestion. The story is similar for freight forwarding and domestic water transport, except that the substitution is mainly indirect, with lower prices in aviation drawing freight away from trucking, and trucking then drawing freight away from domestic water transport. The petroleum products industry is affected by both the decrease in non-aviation transportation and the increase in the efficiency of air transportation.

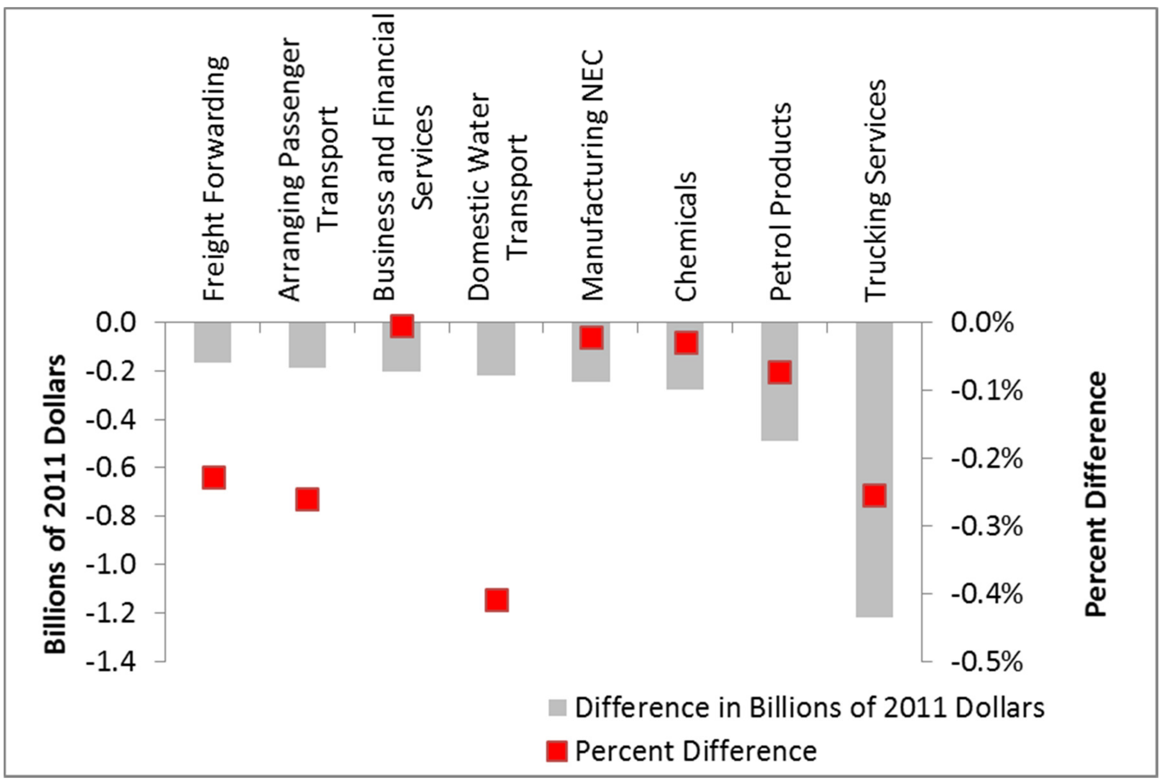

Figure 9. Industries with Lower Growth due to Improved Air Transportation (as measured by output with and without NextGen)

6.3 NextGen's Effect on GDP

In addition to the effect on individual industries, the effect of NextGen on the broader economy is also examined using measurements of GDP. GDP represents the value of the final output of the economy. While it is the single most reported value used to describe the status of an economy, it is not suitable for cost benefit analysis. It is included in this analysis because it is widely understood and of interest to policy makers.

Figure 10 shows that the yearly PDV of increased GDP due to NextGen's effect on the economy is always positive and generally, but not continuously, increasing. As the implementation of NextGen progresses over time, additional capacity is added (and costs incurred) cumulatively but not smoothly, causing the slightly lower yearly increases in GDP in the middle of Figure 10.

The general trend of larger increases in GDP over time with NextGen is driven by the growth in delay in the do-nothing case. Due to the relationships between flights and delay (illustrated in Figures 1 and 2), when capacity is fixed and the amount of traffic increases, the amount of delay increases at an increasing rate. Therefore, in the USAGE-Air simulations without NextGen (i.e., with capacity fixed), each year the amount of delay added to the system is generally higher than the year before. Thus the benefit of the capacity increases from NextGen generally increases each year. The PDV of the cumulative impact of NextGen on GDP from 2010-2030 is approximately $28.2 billion.

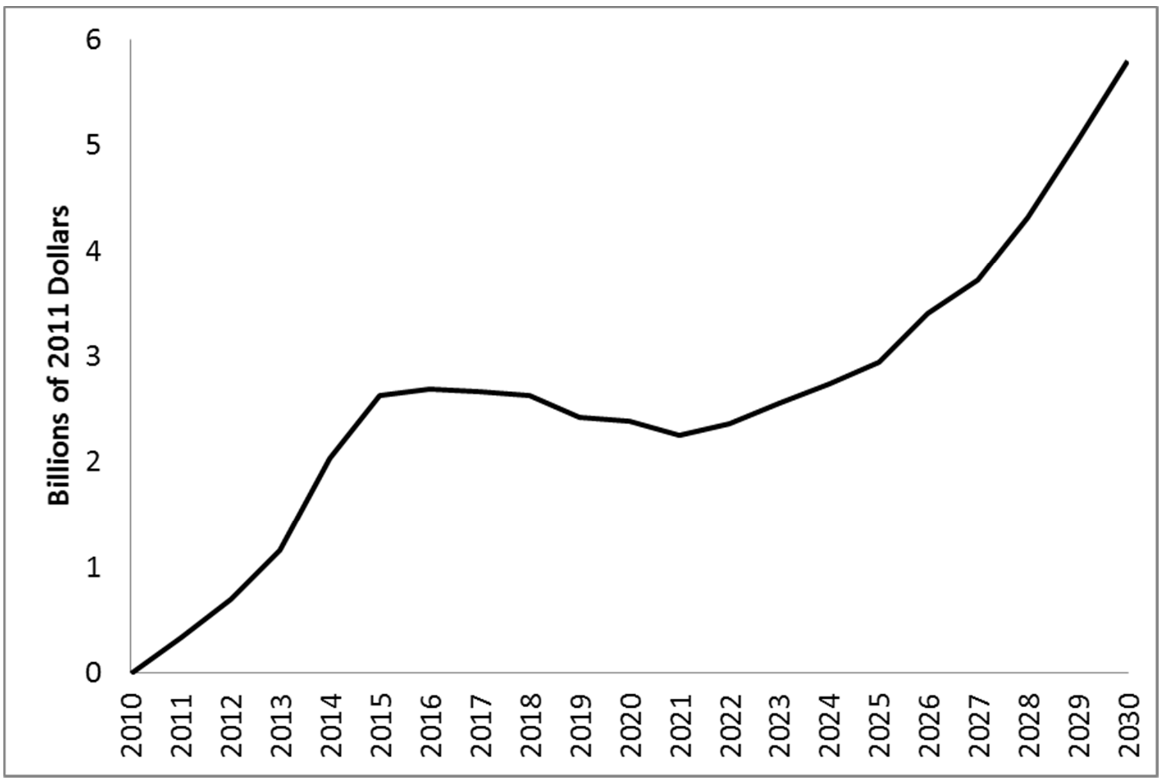

Figure 10. NextGen's Impact on GDP by Year

Of further interest is that NextGen's effect on GDP is consistent regardless of how NextGen is paid for – or even if it is not paid for. In addition to the funding scenario examined in detail in this paper (government raises taxes, air carriers borrow), the model was run with several alternative funding scenarios. In general, the government can raise taxes or engage in deficit spending and the air carriers can borrow or use their cash-on-hand. The tax-borrow scenario was already examined. The analysis was repeated for the remaining possible permutations: tax-cash, deficit-borrow, and deficit-cash. As a fifth scenario, an unrealistic case was analyzed where all of the benefits of NextGen are obtained for no cost (i.e., the capacity enhancement from NextGen is a gift bestowed on the economy with no purchases of actual navigation equipment). Between these five scenarios, the PDV of GDP varied between $26.3 billion (tax-cash) and $29.5 billion (no costs). The scenario discussed in detail in this paper is in the middle of this range. The highest GDP increase comes from the scenario where the benefits of NextGen are obtained for free, illustrating that the model is not subject to multiplier effects. This means the economic benefit of NextGen in the other scenarios is not simply the result of government spending. This is the only relevance for the no cost scenario, so it is not discussed further. Benefits are highest in this case because there is no offsetting to cover costs on the part of air carriers or the government.

The definition of GDP from the expenditure side is shown in Equation 13,

$$Y = C + I + G + (X - M) \tag{13}$$

where Y is GDP, C is personal consumption, I is investment, G is government expenditures, X is exports, M is imports, and (X-M) is net exports. This accounting mechanism allows for an easy explanation for why, in all the funding scenarios, GDP is roughly the same.

GDP increases because of the technology improvement in air transportation (recall Equation 1). When the government's share of NextGen is paid for by taxes, there is the same technology improvement, but the level of consumption goes down (i.e., the government taxes people who have less to spend). However, this decrease in consumption is offset by an increase in spending by the government on NextGen. So, in Equation 13, the increase is government spending is offset by a decrease in consumption, leaving GDP relatively unaffected.

When the government's share of NextGen is paid for by deficit spending, there is an analogous offsetting effect to the one described above. However, because taxes are not increased, the level of consumption remains roughly the same. Instead, the increased government spending is offset by a decrease in net exports. Essentially, the government's deficit spending reduces the amount of domestic funds available for investment. This leads to foreign funds entering the economy and, in turn, appreciates the domestic currency. This appreciation increases imports and decreases exports – i.e., reduces net exports. Thus, the increase in government spending is ultimately offset by a decrease in net exports. The arguments are similar for the share of NextGen paid for by the air transportation industries.

Regardless of the NextGen funding scenario that is assumed, GDP is higher with NextGen than without. Though the impact of NextGen is measured in billions of dollars, it is important to consider the size of the economy to grasp the scale of the effect. This figure is quite small when compared to the roughly $14 trillion GDP that makes up the whole US economy – which is not to understate the importance of NextGen to aviation, but rather to put it in the context of the larger economic landscape. NextGen is important to aviation, and has a broader economic impact, but will not drastically transform the economy.

6.4 NextGen's Effect on Consumer Welfare

While GDP is fairly invariant to the funding scenario chosen for NextGen, the effect on consumer well-being is not. Recall that because markets are assumed to be perfectly competitive, any effect on prices will be passed through to the consumer. In the case of NextGen, more efficient production of air transportation results in lower costs of air transportation – all else equal. In effect, consumers can either buy the same amount of air transportation as before and have money left over to consume other goods, buy more air transportation than before with the same amount of money, or some combination of the two. In the four funding scenarios discussed in the previous section, the increase in consumer welfare measured by the present value of additional consumption with NextGen ranges from a low of $12.5 billion (the tax-cash case) to a high of $28.8 billion (deficit-borrow).

Welfare is higher with deficit spending than taxes because taxes directly impact income and, hence, the ability to consume. Deficit spending, on the other hand, only affects future ability to consume, which is in large part outside of the years modeled. This specific model terminates in 2030, so any future taxes to cover prior deficit spending are not considered.

Starting from the $28.8 billion deficit-borrow scenario and introducing tax collection, the PDV of taxes collected is roughly $12.5 billion which reduces consumer welfare by approximately $11 billion, to $17.8 billion (tax-borrow). Consumer welfare does not decline by the full $12.5 billion because there is some increased income from the government spending those taxes, creating jobs, and generating income for consumers.

Consumer welfare is also affected by how air carriers pay for NextGen. Consumers fare better when the industry borrows to cover its costs because those costs are spread out over time, with some of the burden falling outside the time period analyzed, thus there is less upward pressure on prices. Consumers are able to consume more air transportation and other goods under this case. Continuing the illustration in the previous paragraph, shifting from borrowing to cash-on-hand funding by air carriers reduces welfare gains from $17.8 (tax-borrow) down to $12.5 billion (tax-cash).

These NextGen funding scenarios illustrate that, while GDP is relatively unaffected by the way NextGen is paid for, consumer welfare is affected significantly. Regardless of funding scheme, however, consumer welfare is always higher with NextGen than without. These examples are simply to show that funding mechanisms make a difference, yet the amount of welfare gained from NextGen is significantly positive.

7 Conclusions

This paper makes several contributions to the transportation economics literature. Methodologically, it shows how the outputs from a large, fast-time simulation model of the NAS can be modeled using a simple, modified M/M/1 queuing function – which is subsequently integrated into a CGE model through a technology variable. This function allows for detailed DRTS effects to be modeled for the air transportation industries. This methodology could be applied to any industry that suffers DRTS due to congestion (trucking, waterborne commerce, etc.) and can model the economic outcomes from systemic changes in the nature of the industry's congestion. Further, with respect to methodology, this paper bridges the operational air traffic modeling domain into the CGE domain.

From an applied policy standpoint, this paper makes practical conclusions about the effect of NextGen on various parts of the economy. Unlike a partial equilibrium analysis, the effects are not limited to the directly impacted industry. In addition to air transportation, the effects of NextGen on other industries, consumer welfare, and the entire economy are measured.

The direct impact of NextGen on air transportation is that prices fall approximately 2 percent and output increases approximately $10 billion, cumulatively. Several industries such as foreign vacations (US residents traveling abroad), export tourism (foreign residents traveling to the US), and computers are noticeably stimulated by NextGen. Further, U.S. GDP can be expected to increase by nearly $30 billion and consumer welfare by nearly $18 billion, cumulatively, from the introduction of NextGen (assuming that the government raises taxes to cover the costs of NextGen and the air transportation industry borrows money rather than using cash-on-hand). However, regardless of the funding source used, these figures are expected to be positive.

Finally, while it does not replace standard cost-benefit analyses, a CGE model specifically tailored to model changes to a target industry shows the primary, secondary, and overall effects of policy changes. CBA is very good for examining the impact on the industry being directly affected by a policy change or investment, and can be a useful input to CGE scenario development. However, the effect is largely confined to that industry, and the secondary effects, substitutions to and from other commodities, and effect on the broader economy are unobserved. By supplementing a standard CBA with a CGE analysis, the full effects of a policy can be seen in terms useful to policy makers.

Further extension of this work includes research on the relevance of perfect competition as the governing assumption for the air transport industry (and sensitivity of results to imperfect competition) as well as general ongoing revision of underlying data, forecasts and NextGen implementation assumptions. Outside the scope of this analysis, the methodology could potentially be applied in conjunction with system-performance modeling at the national scale for other modes of transportation or other congestible infrastructure to enrich CGE modeling for a variety of policy and investment questions.

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