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Applications of gravity models to evaluate and forecast US international air freight markets post-GFC

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ABSTRACT

In addition to being the world’s largest economy, the United States (US) has been the foremost driver of consumer spending, free trade and open skies policies. Trade-driven economic growth and air freight markets have been commonly linked in air transport research. Despite increased security after the 9/11 terrorist attacks, international air imports to the US has continued to grow at a rate faster than consumer spending.

This paper aims to evaluate whether gravity models are robust enough to forecast and accurately account for substantial economic shocks such as the Global Financial Crisis (GFC). Our research suggests that US demand for air freight is highly sensitive to transport costs, competition from sea freight and consumer spending patterns of perishable, low value and high value commodities across the 19 commodity groups examined, rather than manufacturing income or factors associated with product origin, which is all the more interesting in the context of the recent protectionist rhetoric of the US administration.

1. Introduction

Considered as one of the world’s most important consumer driven economies, the United States (US) accounts for 13.6% of global imports and US consumers spent over US$4.3 trillion on products in 2018 (Bureau of Economic Advice, 2019), with approximately 15% imported by air from foreign nations (United States Census Bureau, 2019). In addition to being one of the world’s most important consumer driven economies, the US has also, for a long time, embraced the concept of the “free market” in developing economic policy. Free market policies involve the removal of regulatory constraints with the goal of improving commercial competitiveness and delivering overall better economic outcomes. Free trade agreements, and removal of tariffs on imports, are also aspects of regulatory liberalisation that can impact international air freight.

Within the scope of air transport, the concept of “open skies” is a free market policy that commenced domestically in the US under the Air Cargo Act of 1977, which preceded the Airline Deregulation Act of 1978 (Morrell, 2011). The first international open skies agreement signed was between the United States and the Netherlands in 1992. Since 1991, there has been a steady increase to the number of international air cargo routes, with the US leading the way in terms of international routes (Transtats, 2019). In 1991, there were 859 international routes carrying cargo and 2,785 in 2007, and the number of international routes has fallen to 2,096 in 2018 (Transtats, 2019). Unlike the expansion of passenger routes, US international routes carrying cargo have contracted at 0.2% compounded per annum since 1991.

The European Union, as a regional trade zone, followed the US with a number of air transport reforms, developing open skies across Europe and with key trading partners such as the US. To date, 124 nations (including members of the EU-27 and MLIAT members) share a form of open skies arrangement with the US, moreover there are only 14 free trade agreements between the US and 20 other nations (Office of the United States Trade Representative, 2019). Almost 75% of open skies agreements with the US contain 7th freedom of the air rights—the carriage of cargo between the US and another country by an airline foreign to both (US Department of Transportation, 2019). Moreover, these agreements often exclude domestic cabotage (the 8th freedom of the air), protecting domestic (i.e. US) airlines from competition in home markets by international carriers, notably operational restrictions to major cargo
The primary objective of this paper is to examine the US international air freight market just prior to the GFC, throughout the turbulent period that followed, and to the present day and develop a forecasting model that can be applied by practitioners. The timing and impact of the next economic downturn on the air cargo industry may be imminent given the protectionist rhetoric of the current US government (i.e. Trump's tariffs on Chinese imports and other trading partners). Air freight has been commonly linked to economic growth (Tasiaux, 2009; Morrell, 2011; Hakim and Merkert, 2016) and is an important factor to merchandise trade, moving some 35% of the value of merchandise goods globally (Shepherd et al., 2016; ATAG, 2018; IATA, 2018a). Section 2 provides an overview of economic and air freight conditions post-GFC. A literature review on the methodology to be applied, namely gravity models, is provided in Section 3. Development and application of the gravity models will be provided in Section 4. Results and discussion form Section 5, with a conclusion to the research provided in Section 6.

2. Overview and empirical observations of air freight post-GFC

Until 2007, US air imports had steadily increased, reaching a peak at the time of US$415 billion, at 4.3 million tonnes handled. The four largest trading partners with the US, namely China, Japan, Germany and the United Kingdom (UK) accounted for US$168 billion or 40.48% of the value of total US imports by air. From mid-2007 to late 2008, deterioration of financial market confidence in the US triggered the Global Financial Crisis (GFC). The demise of the US financial giant Lehman Brothers in 2008 led to direct and indirect consequences for the air freight industry; firstly constrained inter-bank finance made trade difficult for all commercial operations and secondly Lehman Brothers went bankrupt (Morell, 2011, 2013). In light of the crisis, airlines (amongst others) had to reassess the strength of financial partnerships with their banks. The GFC marked a significant decline in US air imports and consumer spending as illustrated in Fig. 1.

During the GFC, Japan and Germany faced the biggest declines in air cargo trade value with the US, dropping 27.24% and 23.96% respectively. In 2008 US air imports dropped by 10% in volume. Company inventory levels were reduced during this period, and new purchases deferred, impacting international trade and further contributing to declines in air freight. Air freight value (and volume) would both be impacted by these business decisions made due to lower consumer confidence, both during and immediately after the events of the GFC. In 2009, at the peak of the GFC, US air imports had dropped in total value by over 10% to US$367 billion and volume declined by over 25% to 3.2 million tonnes (United States Census Bureau, 2019). Moreover, Japan (US$35.3 billion in air freight trade to the US in 2018) and South Korea (US$20.4 billion), have faced regional competition from China (US $157.6 billion) and subdued growth over the last decade in air freight trade value with the US (United States Census Bureau, 2019).

Merkert et al. (2017) further highlight an important link between air freight and global share of manufacturing and silicon material shipments in particular are considered by IATA (2017) as an important stimulant to demand for air freight. Despite the impact of the GFC and high oil prices afterwards, China has continued to grow their manufacturing capabilities, especially producing consumer electronics such as the iPhone, laptop computers and other high-tech audio-visual equipment. As the most important trading partner to the US in more recent years, China has increased overall market share of air cargo imports to the US from 17.8% in 2007 to 23.7% in 2018 and shipped over 1 million tonnes of commodities by air, worth over US$120 billion, every year since 2012 (United States Census Bureau, 2019), greater than the combined value of the next four major trading partners to the US-Japan, Germany, the United Kingdom and France. China’s increasing trade profile has also had a significant regional impact, with air freight trade value between Asia and the US doubling since 2003 as shown in Fig. 2.

Following the GFC, US air imports rebounded by over 21% in total value and 25% in total volume in 2010, recovering from the decline of 2008/09. US international air freight import value increased again in 2011, by over 11%, despite a reduction in volume of almost 5%. Stagnant growth in volumes post-GFC could be attributed to several macroeconomic factors-higher oil prices, attention on US budget deficits and continued trade imbalance (the “fiscal cliff”), low consumer confidence, as well as continued regional economic crises amongst trading nations (such as the European sovereign crisis). Brent crude rose above US$100 per barrel in 2012/13 and remained so until late 2014 (NASDAQ, 2019), and potentially as a result there was minimal growth in US air imports for this period.

Kupfer et al. (2017) express a strong relationship between air freight and trade, noting that the price of oil and air cargo yields have a significant impact to air cargo, despite the fact that airlines can utilise financial instruments such as hedging to mitigate costs, operationally introduce fuel surcharges or cross-subsidise belly-hold freight capacity with passenger volumes above break-even margins (passenger load factors for flights have hit a July peak load factor record of 85.2%, IATA, 2018b). In the latter half of 2014, the benchmark Brent crude oil price...
began to drop to below US$60 per barrel, providing cost relief for airlines and the air freight industry (amongst others). US air freight imports continue to grow with Brent crude reported at just over US$63.42/barrel recently (November 15th, 2019 pricing, NASDAQ, 2019).

Additional to the premium costs involved with air freight is a market facing overcapacity, principally from wide-bodied commercial jets scheduled for passenger transport, as belly-hold space is often considered as a by-product of these flights. Industry wide freight load factors continue to stabilise below 46% of available freight tonne-kilometres (IATA, 2018). Weaker market conditions have led to the grounding of some 87 (Kauffman, 2019) of the 1,870 strong dedicated freighter fleet globally (Boeing, 2018), and increases to the total payload capacity for freighters has been stagnant (IATA, 2017). Despite these shortfalls, route densities exist, with utilisation of dedicated freighter aircraft at over 80% capacity between some country-pairings from South Korea in particular (Merkert and Alexander, 2018). Moreover, in 2018, air transport carried over 4.9 million tonnes of merchandise trade imports to the US, 50% more than in 2009, and this cargo was worth a staggering US$664 billion, almost double the value of imports by air to the US in 2009 (United States Census Bureau, 2019).

3. Literature review of gravity models

Gravity models, named for the theory of gravity by Sir Isaac Newton, were borrowed from the school of physics and incorporated into the school of economics under theories such as the law of retail gravitation, developed by Reilly in 1931. This theory was further developed into the gravity model of trade in 1962 (Anderson and van Wincoop, 2003), and has been utilised in a variety of ways by major institutions such as The World Bank, World Trade Organisation (WTO), Airports Council International (ACI) and IATA within air transport research.

Development of gravity models combine generating factors (such as population and/or economic size) and impedance factors (such as distance and/or cost). The flexibility of the gravity model, ease of development and growing success of its application are three factors that favour its deployment. The traditional gravity model of trade (Head, 2003) follows the algebraic form:

\[ F_{ij} = GM_i^\alpha M_j^\beta d_{ij}^{-\theta} \]  

(1)

where \( F_{ij} \) represents the interaction between two independent regions, \( i \) and \( j \), \( G \) a constant (or weighting factor), \( M \) represents size of the region (population or economic value such as GDP), \( d \) represents distance between the two independent regions and \( \alpha, \beta \) and \( \theta \) representing factorial components, designated as positive for attraction and negative for impedance (Alexander and Merkert, 2017). This initial model includes elasticities and considers bilateral trade flows.

Gravity models have been used in air cargo research, either inclusive of air passenger transport services (Matsumoto, 2004, 2007; Matsumoto and Domae, 2018, 2019) or independently (such as by Yamaguchi, 2008; Achard, 2008; Gong et al., 2014; Vega, 2014; Gong et al., 2018); as a means of comparison with other modes to air transport (Quandt and Bauml, 1966; Feyrer, 2009; Gadala-Maria, 2014; Avetisyan and Hertel, 2015) and air traffic forecasting (Long, 1970; Turner, 2001; Bhadra and Kee, 2008; Srindhi and Mannari, 2014; Xia and Yu, 2015).

Matsumoto (2004) uses gravity models to assess air transport flows of international air passengers and cargo across Asia, Europe and America between 1982 and 1998, finding that concentration of air traffic had strengthened around core hubs during this time period. Matsumoto (2007) followed his earlier research by separating air passenger and air cargo traffic at the international level, finding a small, but counterintuitive, coefficient for the impact that distance has on cargo volumes, which may be a result of unobserved factors within his study. Yamaguchi (2008) utilised gravity model applications to assess US exports and air transport policies such as “open skies” to 21 trading partners. Yamaguchi found that “open sky” markets increased air cargo unit costs, possibly as a result of congestion in core hubs previously documented by Matsumoto (2004). These findings appear counterintuitive to a primary goal of air transport liberalisation in fostering competition, which should decrease cost, for the benefit of consumers (Iches, 2010). Achard (2008) develops a gravity model to assess air transport liberalisation on international air cargo flows, finding GDP to be a counterintuitively negative factor, whilst noting that substitution to surface transport modes may impair his results. Vega (2014) developed gravity models for trade between developing countries and established mega-economies such as the US and European Union with GDP per capita, distance, population, air freight rates, and with dummy variables for liberalisation (open skies), landlocked or island nations. An interesting finding of his research is that for a one percent increase in GDP per capita, perishable exports appear to increase by just 0.78% and high value exports by 2.93%.

Gong et al. (2014) used gravity models to assess the position of Chinese airlines in the air cargo industry, as China is a manufacturing conglomerate. Their findings indicate that the coefficient estimations are “intuitively correct”, with GDP representing a significant attractive factor and conversely cross-border activity and distance as impediments. Gong et al. (2018) follow with a study on China air cargo networks with an augmented gravity model utilising GDP, population and culture as

![Fig. 2. Air freight imports to the US by region and value, 2003-2018 (Source: Compiled by data from United States Census Bureau (2019).)](image-url)
socioeconomic variables. The authors conclude with the statement “Chinese airlines and logistics operators still play relatively minor roles in the global air cargo market” which is interesting considering China-US air freight was worth over US$120 billion since 2012 (United States Census Bureau, 2019).

Matsumoto and Domae (2018) utilise the gravity model formulation to assess how international air traffic flows have impacted the hub status of cities in East and SouthEast Asia between 1982 and 2012. They find that distance for selected cities, somewhat counterintuitively, had a positive impact to air cargo volumes. This may be due to the selection of air routes (short haul, medium haul and long haul); competition by other transport modes (sea, road or rail); and/or a result of incorrect evaluation of observed (or unobserved) factors that may occur within fixed effects modelling. Matsumoto and Domae (2019) use a similar gravity model formulation finding that generative factors of GDP and population had reduced after the year 2000, which may simply be a result of the changing components of GDP and why a more direct measure, such as consumer spending on goods (imports) and transportation services, should be considered for future air passenger and air cargo gravity models.

The Quandt and Baumol (1966) augmented gravity model incorporated key determinants such as population, GDP, GDP/capita, distance, as well as cost and time function trade-offs between the preferred transport mode and the best available transport mode. Their gravity model is formalised as:

\[ F_{ijm} = \frac{K P_i^a P_j^b Y_i^c Y_j^d M_i^e M_j^f N_i^g N_j^h (T_{ijm})^I (C_{ijm})^J (C_{ijm})^K}{(T_{ijm})^L (C_{ijm})^M} \]  

(2)

With F representing volume, i and j representing two independent regions, P representing population, Y gross regional product, M industrial activity, N modal activity, T time, C cost, b as the lowest factor, m as the modal attribute. Factors influencing the model are included as K (a constant), a, b and γ. For this model to work in a multimodal environment, it should be noted that \((T_{ijm})^{L2} (C_{ijm})^{11} \neq (T_{ijm})^{10}(C_{ijm})^{12}\). Fevre (2009) used gravity models to estimate trade flows between air and sea modes to the United States between 1955 and 2004, finding an increase in importance to air traffic. Gadala-Maria (2014) evaluated ocean and air infrastructure impacts to trade utilising gravity models and found that shared language and currency improves trade flow between nations, confirming the work of Shepherd (2013), Avetisyan and Hertel (2015) developed a Constant Elasticity of Substitution model to assess transport mode substitution between air-sea and air-land modes with a gravity model formulation.

Long (1970) potentially conducted the first air transport forecasting research using gravity models, providing a ranking of cities by mean absolute percentage error (MAPE). Turner (2001) used an augmented gravity model for forecasting international air freight from Vancouver International Airport in 1998. Turner (2001) found that additional explanatory variables should be utilised in addition to population (M), income (GDP/capita as y), distance (d), CPI differential (C) and tariff barriers (T). Turner (2001) used the following derivative of a gravity model as a result:

\[ F_i = \frac{M_i^a M_j^b Y_i^c Y_j^d (T_{ijm})^I (C_{ijm})^J (C_{ijm})^K}{d_i^d C_j^e T_j^f} \]  

(3)

within air transport, forecasting is potentially fraught with difficulties. Notably examples are within air passenger forecast models impacted by numerous psychological factors (terrorism such as 9/11, SARS etc), whilst air cargo is predominantly impacted by financial crisis (GFC). Bhadra and Kee (2008) reported that an FAA forecast for 2015 US commercial aviation would exceed one billion passengers, up from 750 million in 2006. The Global Financial Crisis, which triggered a 10% decline in air passenger travel in the US during 2008–2009, coupled with a mature air market in the US has only recently seen this figure surpass 889 million (World Bank, 2018a).

Forecasting can also lead to high volatility and significant errors, as

Srndhi and Manrai (2014) developed an aggregated demand model for the international air passenger market in India, supplying a range of forecasts from 24 million to 93 million, from a base of 40 million. Xia and Yu (2015) utilise gravity models to assess the importance of Macau as a strategic gateway between China and Portuguese speaking countries based on 2012 air passenger flows. Using the 2013-14 growth rate of 37% as a static figure, from a low passenger base, the forecast projections of Xia and Yu (2015) became unrealistic to achieve.

Kuper et al. (2017) developed an error correcting model for forecasting air cargo demand, linking merchandise exports to air freight tonne-kilometres. This model was designed for medium term forecasting projections only, considering several scenarios, such as growth in merchandise trade and oil price, two scenarios of stagnation, moreover a combined scenario of stagnant oil price and merchandise trade was not considered (especially notable given the protectionist rhetoric of the Trump administration). All of the projections are straight line, and thus do not consider the impact of an economic event, such as the GFC.

Estimation of gravity models in air transport research predominantly focus on the Ordinary Least Square (OLS) regression technique (Gong et al., 2018; Matsumoto and Domae, 2018, 2019). Shepherd (2013) confirms that the general approach for gravity modelling estimations is a log-linear formulation and use of the Ordinary Least Squares (OLS) regression technique, sometimes with fixed effects. Fixed effects typically segregate aspects of a region or location and have been applied in air transport research at the regional block level (Vega, 2014), national level (Gadala-Maria, 2014), regional level (Gong et al., 2018) or city level (Matsumoto and Domae, 2018, 2019). Cohen (2016) finds that the PPML estimation does not improve the quality of his forecast model over OLS and states that “OLS is the preferred model” when comparing results with Mean Average Percentage Error (MAPE). Moreover, in an industry that is measured globally in millions of tonnes (IATA, 2018a), billions of freight tonne-kilometres (World Bank, 2018b) and trillions of US dollars carried (ATAG, 2018), zero trade flows suggests that there simply is no market. As a result, it remains debatable as to the effectiveness of PPML estimations over OLS.

4. Methodological development

The aim of this research is to examine US international air freight import markets and consumer spending during the period encapsulating the GFC. This includes a few years prior to the GFC (2005–2007), the turbulent impacts of the events during the GFC (2008–2009) and the aftermath of the GFC from 2010. Based on research into causality between air transport and economic growth by Hakim and Merkert (2016) which indicates a 3–4 year time lag, the year 2005 was taken as a baseline year for this analysis into the impacts of the GFC on US international air freight imports.

Imported commodities range from food products (meat, dairy, fruits and vegetables etc.) to general household items and high value luxuries. Air freight typically involves products that may be time-definitive (such as perishable commodities, objects with high obsolescence and/or sensitive items), security conscious (high value items) and/or of a light encumbrance (including weight and/or cubic dimensions) (Merkert et al., 2017). Especially during economic crisis, products are more likely to be sourced from the cheapest producer, including foreign exchange rates and transport costs, rather than based on other consumer attributes (i.e. quality of produce). Competition between suppliers leads to market substitution either within a region (such as switching from Japanese and Korean electronics to Chinese), or between regions that provide homogenous goods. Product substitution involves switching between comparable products (i.e. consumption of meat products or acquisition of clothing attire). Some peripheral air freight markets are also susceptible to transport mode substitution.

Data sourced from the US Census Bureau indicate 278 US airports handled international air freight in 2005. As indicated previously, air cargo routes appear to be more focussed than passengers, and only 36
airports handled 3,000 tons or more in air freight imports in 2005. These
airports accounted for US$354 billion and 3.92 million tonnes of US air
imports, representing 98.8% by value and 98.9% by volume respecti-
vely. Moreover, several US districts (such as New York, San Francisco,
New Orleans and Cleveland) are home to multi-airport regions that deal
with large volumes of air cargo imports.

From the 225 international trading partners to the US with registered
air freight volumes, some 72 nations reported at least US$100 million of
air freight trade value to the US in 2005 (US Census Bureau, 2019).
Despite the sizeable amount of trade, Bangladesh, Botswana, Cambodia,
Indonesia, Iraq, Malta, Pakistan, Romania, Slovenia, and Sri Lanka had limited direct flights (based on data from Transtats,
2019a) carrying cargo to the US mainland and were removed from the
sample. The nation of Venezuela was also removed from the data set, as
the nation also experienced currency hyperinflation in 2006, changed
market share of air cargo transport by US consumer spending, 2018

A gravity model was developed to identify the key attributes that
may attract or impede US international air freight markets. Key attrac-
tive factors for this gravity model included consumer spending, trans-
port costs, which are expected to have a positive impact to air cargo as
this mode attracts the greatest premium, and free trade agreements
that should be expected to facilitate trade between nations through removal
of tariffs. Key impediments of this model include sea freight, through
modal competition and substitution, distance as a usual impediment and
landlocked nations, as the provision of road and rail transport competes
with air cargo. Dummy variables for region and if the nation held En-
glish as a first language were included. Grosso and Shepherd (2009)
found that colonisation, somewhat counterintuitively, had a negative
impact to trade within the APEC region, although this may have also
been correlated to common language. Equation (4) presents the initial
log-linear gravity model formulation utilised in this study:

| Commodity Group | HS Codes | Category | Total US Customs Value ($b, 2008) | Total US Customs Value ($b, 2018) | Market share of International air cargo to US by Region (2018) |
|-----------------|----------|----------|----------------------------------|----------------------------------|---------------------------------------------------|
| Meats, fish, seafood, milk, dairy, eggs and poultry | 01-04, 16 | Perishables | 23.68 | 36.98 | 11.56% 10.95% 2.72% 3.89% 31.55% 35.70%  |
| Plants, fruits, vegetables and seeds | 06-08, 12, 13, 20 | Perishables | 23.32 | 42.58 | 6.25% 4.88% 6.88% 8.50% 14.89% 14.35% |
| Coffee, tea and related products | 9 | Perishables | 5.17 | 7.82 | 7.05% 45.23% 5.18% 16.28% 4.34% 0.45% |
| Gereals and Bakery Products | 10, 11, 19 | Perishables | 7.96 | 12.35 | 0.41% 4.23% 0.25% 0.15% 0.69% 4.91% |
| Fats and Oils | 15 | Perishables | 5.29 | 6.88 | 0.83% 0.68% 0.36% 40.13% 1.30% 1.18% |
| Miscellaneous | 21 | Perishables | 3 | 7.75 | 3.68% 0.61% 2.42% 10.98% 13.00% 3.28% |
| Tobacco | 24 | Low value to weight | 1.46 | 2.2 | 5.68% 0.09% 7.77% 0.00% 7.45% 6.43% |
| Cosmetics, household cleaning and misc. manufactured articles | 33, 34, 96 | Low value to weight | 14.11 | 24.9 | 11.65% 39.57% 8.45% 32.24% 19.41% 9.34% |
| Film and Printed materials | 37, 48-49 | Low value to weight | 25.36 | 23.4 | 8.47% 9.39% 10.72% 30.95% 16.41% 5.06% |
| Automotive | 40, 87 | Low value to weight | 215.41 | 328.95 | 1.29% 1.65% 1.13% 14.03% 4.43% 1.93% |
| Clothing, clothing materials, footwear and accessories | 41-43, 50-56, 58-67 | Low value to weight | 128.19 | 158.75 | 14.01% 15.11% 10.14% 36.91% 64.75% 9.76% |
| Household furnishings | 57, 94 | Low value to weight | 40.53 | 70.42 | 3.58% 8.06% 1.94% 35.41% 22.30% 12.48% |
| Household items (non audio-visual) | 69, 70, 73, 82, 84 (excluding nuclear- 8401) | Low value to weight | 304.12 | 444.54 | 30.16% 13.95% 37.58% 35.68% 40.23% 11.23% |
| Outdoors and recreational items | 92, 93, 95 | Low value to weight | 35.6 | 37.26 | 8.84% 28.68% 5.46% 50.78% 41.89% 50.25% |
| Pharmaceuticals | 30 | High value to weight | 52.34 | 114.99 | 72.42% 27.14% 67.95% 93.17% 77.88% 29.43% |
| Jewellery | 71 | High value to weight | 49.53 | 60.02 | 85.91% 95.30% 94.03% 80.61% 93.87% 93.46% |
| Audio-visual, photographic and medical equipment | 85, 90 | High value to weight | 308.85 | 452.68 | 50.33% 79.78% 58.10% 67.12% 77.27% 31.80% |
| Aircraft and parts | 88 | High value to weight | 21.52 | 31.77 | 36.86% 72.37% 53.37% 21.68% 43.79% 7.29% |
| Watches and Clocks | 91 | High value to weight | 4.03 | 4.46 | 86.68% 18.77% 66.73% 100.00% 97.19% 48.65% |

To identify the potential of substitution of products, transport mode and
markets, and reconcile with consumer spending categories (US Bureau of
Economic Analysis), similar product types (such as meats, clothing)
were grouped together, total import market and air freight market share
were identified and regions of importance were highlighted in Table 1A.
A total of 19 commodity groups were developed, combining a total of 62
HS chapters that are potentially significant to air freight.

### 4.1. Model formulation

The market share of International air cargo to US by Region (2018)
with $AF_{ij}$ as air freight value (or volume) between countries $i$ and $j$ of product $p$, CS as Consumer spending, TC as transport costs, with regional fixed effects for the Middle East (ME), Southern Europe and North Africa (WestMed) and other regional locations, and Com$_{man}$ for common first language (English) between the two trading partners. Results of the gravity models are presented in Table 2 and Appendix 1.

Wang et al. (2013) studied forecasting of passenger and freight traffic using elasticity coefficient methods with static and dynamic elements. They provide the following formulation for forecasting future market values:

$$F_t = F_t(1 + Eq)^r$$

(5)

with $F_t$ and $F_t'$ representing market values at $t$ and $t'$ respectively, $E$ as the elasticity coefficient and $q$ as rate of economic growth at time $t$. Note that the formula provided by Wang et al. (2013) is very similar to that provided by Hakim and Merkert (2016; Kupfer et al., 2017) was developed considering the most significant items, transport costs and consumer spending as attractions for air cargo and sea freight as an impedance factor as:

$$\ln AF_{ij}(t) = n \ln(AF_{ij}(t-1) + \Delta CS_{ij}(t) + \Delta TC_{ij}(t) + \Delta SeaFreight_{ij}(t)) + \epsilon$$

(6)

where $AF_{ij}$ is the market value (or volume) of the commodity at time $t$, $n$ as a coefficient of the equation, with changes to US consumer spending (CS), rather than GDP, and transport costs as generative factors and sea freight value (or volume) as the key impediment, with an error term ($\epsilon$). Due to the size of the sample (59 countries, 19 commodity types) and based on values from the largest US trading partner, China, changes to transport costs were capped between 28% and -10% and sea freight volumes were capped between ±35% and -25%.

Omissions from the gravity modelling consideration were manufacturing income (which is not fully exclusive to international air freight and also combines domestic consumption and inventories with merchandise exports that go to the world market) and the GFC as an independent variable (as the aim is to assess a model for identifying air freight market impacts by economic crisis or boom in future without the foresight of the event taking place).

4.2. Data scope and limitations

Research into the US air freight industry is assisted by three quality data portals, firstly the US Census Bureau (www.census.gov), secondly the US Bureau of Economic Analysis (www.bea.gov) and finally the US Bureau of Transportation Statistics (BTS) Transtats portal (www.transtas.BTS.gov). The US Census Bureau provides significant data on the value and volume of international air freight imports and exports by Harmonized System (HS) commodity codes, with country and region specifications, monthly or annual time periods from 2003 and with only a two month lag in reporting. Moreover, whilst some data is at port level, not all data is available at this level of disaggregation and thus restricted this analysis to the district level.

Supplemental data, such as US consumer spending and GDP, was sourced from the Bureau of Economic Analysis (www.bea.gov). The Bureau of Economic Analysis provides annual, quarterly and monthly data on the economic condition of the US, moreover the quarterly and monthly data are seasonally adjusted to the annual figure, rather than discrete values reported in the quarter or month. The BTS Transtats portal provides access to data on air transport via the Air Carrier Statistics (Form 41 Traffic)-All Carriers database, although there is a six month lag from reporting of activity. Free trade agreements were available from the Office of the United States Trade Representative (www.ustr.gov).

5. Results and discussion

After calibrating the model to the baseline 2005 figures for the 19 commodity groups of the three separate markets-perishables, high value and low value air freight, the forecast model was applied across the 2006–2018 timeframe. Mean average percentage error (MAPE) for the 2006 and 2018 forecasts is indicated in Table 3. Weightings based on the 2006 forecast were then applied to six categories over US$1 billion in air cargo, low value commodities: furnishings (1.2) and outdoors (1.4), whilst high value commodities: jewellery (0.93); aircraft (0.87); and watches (1.16) were appropriately weighted. Weighting was initially applied to household items, based on 2006 MAPE, moreover this had a substantial impact to the forecast results for 2007 and was subsequently removed.

Perishable products and products with low overall market value were not adjusted (such as tobacco), as in some cases the total value of the market was less than 1% of the aggregate. Consumer electronics equipment (audio-visual) represented a large share of the high value air cargo markets, as represented in Fig. 3. Notably, the forecasting model tracked the economic downturn of high value air cargo markets facilitated by the GFC, as well as the post-GFC rebound in 2010. Similarly to consumer electronics, household items, the next largest US international air import market by total value, experienced the economic downturn, recovery and several other boom/bust periods since, as indicated in Fig. 4. Results of forecasting for various other markets are located in Appendix 2.

6. Conclusions

This paper sought to model the impacts of consumer spending on air freight import values to one of the world’s largest economies, the United States. The Global Financial Crisis had a significant impact to consumer spending and as a result, demand in air cargo markets. International trade with the US remains a significant concern for many foreign trading
partners, especially with the current rhetoric of the Trump administration. Notably, consumer spending in the US has continued to grow, despite the GFC impact of 2009, as has imported goods. Perhaps more importantly this research has shown that the developed gravity models are robust enough to handle and accurately account for substantial shocks such as the GFC. At the aggregate level, the value of air freight imports with the US appears to be reasonably forecastable utilising the gravity model approach. At a somewhat disaggregated level, the gravity model was also noticeably effective, although some improvements can be made to the forecasting methodological approach and refinement of data. Notably, whilst the model was developed to identify the economic impact of the GFC, the forecast models appear to have identified several more boom/bust periods for low and high value commodities in the air freight market.

Given the focus of our paper on the air cargo import market of the US only, further research is required into the development of gravity models that may assist stakeholders in global air cargo markets and international supply chains. Beyond the scope of this paper was air cargo imports to European and North East Asian markets, notably the other two major economic regions of the world, and cross-elasticities of imported products (for example between meat and vegetables) to the US. It is further worth noting that at the time of receiving the proofs for our manuscript in April 2020, COVID-19 had a major impact on the air cargo industry both in the US and globally. We strongly believe that our hypothesis will hold for pandemics such as COVID-19 too, which would highlight the value of gravity models in forecasting during disruption and exogenous shocks to airline markets. Further research in this regard is needed once the data becomes available.

Table 3

| Commodity Group | 2006 (US$m) | 2006f (US$m) | 2006 MAPE | 2007 (US$m) | 2007f (US$m) | 2007 MAPE |
|-----------------|-------------|-------------|-----------|-------------|-------------|-----------|
| Meats et al.    | 1,570.65    | 1,541.73    | 1.84%     | 1,763.10    | 1,736.84    | 1.49%     |
| Plants et al.   | 1,487.58    | 1,481.60    | 0.40%     | 1,581.61    | 1,685.70    | 6.58%     |
| Coffee et al.   | 31.44       | 27.67       | 11.97%    | 34.84       | 31.82       | 8.69%     |
| Cereals et al.  | 33.22       | 25.79       | 22.35%    | 55.05       | 43.29       | 21.37%    |
| Fats and Oils   | 15.67       | 45.42       | 189.82%   | 22.09       | 20.30       | 8.11%     |
| Miscellaneous   | 121.54      | 98.52       | 18.94%    | 148.60      | 156.58      | 5.37%     |
| Total Perishables | 3,260.10    | 3,220.74    | 1.21%     | 3,605.30    | 3,674.52    | 1.92%     |
| Tobacco         | 90.50       | 108.75      | 20.16%    | 89.31       | 99.48       | 11.38%    |
| Cosmetics et al.| 1,369.62    | 1,383.71    | 1.03%     | 1,427.83    | 1,434.21    | 0.45%     |
| Film            | 1,331.71    | 1,346.73    | 1.13%     | 1,451.52    | 1,298.51    | 10.54%    |
| Auto            | 2,348.31    | 2,353.44    | 0.22%     | 2,935.10    | 2,371.85    | 19.19%    |
| Clothing        | 17,485.82   | 17,257.79   | 1.30%     | 16,920.80   | 16,542.88   | 2.23%     |
| Furnishings     | 1,085.17    | 886.20      | 18.34%    | 1,276.80    | 995.51      | 22.03%    |
| Household       | 91,393.80   | 82,699.98   | 9.51%     | 95,664.36   | 90,825.80   | 5.06%     |
| Outdoors        | 4,342.56    | 2,957.59    | 31.89%    | 3,529.30    | 3,610.94    | 2.31%     |
| Total Low Value | 119,447.49  | 108,992.19  | 8.75%     | 123,295.02  | 117,179.19  | 4.96%     |
| Pharm           | 31,300.64   | 31,894.14   | 1.90%     | 34,618.37   | 37,395.21   | 8.02%     |
| Jewellery       | 35,971.35   | 38,579.24   | 7.25%     | 39,439.67   | 49,942.11   | 26.63%    |
| AV              | 130,781.09  | 127,200.40  | 2.74%     | 134,860.56  | 134,869.28  | 0.01%     |
| Aircraft        | 3,372.78    | 3,869.61    | 14.73%    | 4,283.34    | 4,876.22    | 13.84%    |
| Watches         | 3,076.69    | 2,640.59    | 14.17%    | 3,508.47    | 3,050.51    | 13.05%    |
| Total High Value| 204,502.55  | 204,183.97  | 0.16%     | 216,710.42  | 230,133.33  | 6.19%     |

Fig. 3. Audio-Visual and Total high value air cargo markets.

Table 3: Raw forecast model results, 2006 and 2007.
CRediT authorship contribution statement

D.W. Alexander: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. R. Merkert: Writing - review & editing, Supervision.

APPENDIX 1

Table A.1
Perishable gravity model estimations

| Model            | Perishable ($) 2005 (Adjusted R² = 0.529) | Perishable (kg) 2005 (Adjusted R² = 0.587) |
|------------------|------------------------------------------|-------------------------------------------|
| Fitness          |                                          |                                           |
| Constant         | -9.596                                   | -5.563                                    |
| ln CSj (US)       | 0.631***                                 | 0.461***                                  |
| ln Seafreightij  | -0.439                                   | -0.954***                                 |
| ln TCij           | 1.375***                                 | 1.588***                                  |
| ln dij            | -0.801                                   | -0.936                                    |
| FTAij             | 1.318**                                  | 1.001*                                    |
| Middle East       | -1.610                                   | -0.603                                    |
| South/SouthEast Asia | -1.871                                   | -1.153                                    |
| NE Asia           | 0.683                                    | 0.255                                     |
| Central America   | -2.532                                   | -0.906                                    |
| South America     | -0.129                                   | 0.684                                     |
| Eastern Europe    | -0.758                                   | -0.673                                    |
| Central Europe    | 2.239*                                   | 1.553                                     |
| Northern Europe   | 0.265                                    | 0.287                                     |
| Southern Europe/North Africa | -0.768                           | -0.489                                     |
| Common languageij | 2.428                                    | 1.958                                     |
| Landlockedij      | -3.947                                   | -4.523**                                  |

Note: * significant at p < 0.1, ** significant at p < 0.05, *** significant at p < 0.01.

Table A.2
Low Value gravity model estimations

| Model            | Low Value ($) 2005 (Adjusted R² = 0.799) | Low Value (kg) 2005 (Adjusted R² = 0.816) |
|------------------|------------------------------------------|-------------------------------------------|
| Fitness          |                                          |                                           |
| Constant         | -15.632                                  | -10.574                                   |
| ln CSj (US)       | 0.822***                                 | 0.477**                                   |
| ln Seafreightij  | 0.020                                    | -0.081                                    |
| ln TCij           | 0.983***                                 | 0.974***                                  |
| ln dij            | -0.599                                   | -0.296                                    |
| FTAij             | 0.270                                    | 0.106                                     |
| Middle East       | 0.532                                    | 0.205                                     |
| South/SouthEast Asia | -0.940                                   | -0.700                                    |

(continued on next page)
Table A.2 (continued)

| Model                        | Low Value ($) | Low Value (kg), 2005 |
|------------------------------|---------------|----------------------|
| NE Asia                      | -0.365        | -0.229               |
| Central America              | -1.602*       | -1.090               |
| South America                | -0.865        | -0.401               |
| Eastern Europe               | 0.135         | 0.150                |
| Central Europe               | 1.225**       | 0.835                |
| Northern Europe              | 0.414         | 0.038                |
| Southern Europe/North Africa | 0.085         | -0.134               |
| Common languages \( l_j \)   | 0.943         | 0.778                |
| Landlocked                  | -1.098        | -1.024               |

Note: * significant at \( p < 0.1 \), ** significant at \( p < 0.05 \), *** significant at \( p < 0.01 \).

APPENDIX 2

Major US imported perishable air cargo commodities

Total US perishable air imports vs Aircraft imports (High Value)
Various US air imports of low value to weight

US high value air imports, Pharmaceuticals vs Jewellery.

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