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The Asymmetric Effects of Income and Fuel Price on Air Transport Demand

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Note: There will still be some minor changes made to this manuscript prior to final publication.

Abstract

Forecasts of passenger demand are an important parameter for aviation planners. Air transport demand models typically assume a perfectly reversible impact of the demand drivers. However, there are reasons to believe that the impacts of some of the demand drivers such as fuel price or income on air transport demand may not be perfectly reversible. Two types of imperfect reversibility, namely asymmetry and hysteresis, are possible. Asymmetry refers to the differences in the demand impacts of a rising price or income from that of a falling price or income. Hysteresis refers to the dependence of the impacts of changing price or income on previous history, especially on previous maximum price or income. We use US time series data and decompose each of fuel price and income into three component series to develop an econometric model for air transport demand that is capable of capturing the potential imperfectly reversible relationships and test for the presence or absence of reversibility. We find statistical evidence of asymmetry and hysteresis – for both, prices and income – in air transport demand. Implications for policy and practice are then discussed.

Keywords

Air transport demand, imperfect reversibility, asymmetric response, hysteresis, econometric modelling

The Asymmetric Effects of Income and Fuel Price on Air Transport Demand

1. Introduction

Demand for air transport has been ever increasing, most recently being driven by the emerging economies in the world. For example, during the last decade, world-wide air traffic grew by 5%: China and Brazil's domestic market grew by 9.5% and 8.6% respectively, while the mature US domestic market grew by only 0.8% (International Air Transport Association 2013). Such possible changes in air transport demand in the future are an important planning parameter. Long term demand forecasts are often required for infrastructure planning on capacity expansion or modification and are primarily used by government agencies or airports. On the other hand, short term forecasts are important for operational planning, including airlines' route choice, pricing and revenue management planning. Because of this importance of demand forecasts, there is a substantial literature on air transport demand modeling (e.g. Profillidis 2000, Lim et al. 2008, Tsekeris 2009, Department for Transport 2009, Wadud 2011 and 2013) and, like most other demand models, all of these are based on the assumption of a perfectly reversible and symmetric relationship between demand and its drivers. However, such an assumption has been challenged in other economic relationships in the area of transport and energy, such as those between oil price and energy demand (e.g. Dargay 1992, Gately 1992) or economic output (e.g. Serletis and Istiak 2013), and between income and car ownership (e.g. Pendyala et al. 1995, Dargay 2001). Along the same vein, it is possible that air transport demand can also show an imperfectly reversible or asymmetric relationship with respect to fuel price and/or income. In this paper we explain why such an asymmetry may hold for air transport demand, empirically investigate the presence or absence of such an effect and discuss the potential consequences. To our knowledge, this is the first study to have empirically investigated imperfect reversibility in the context of air transport demand.

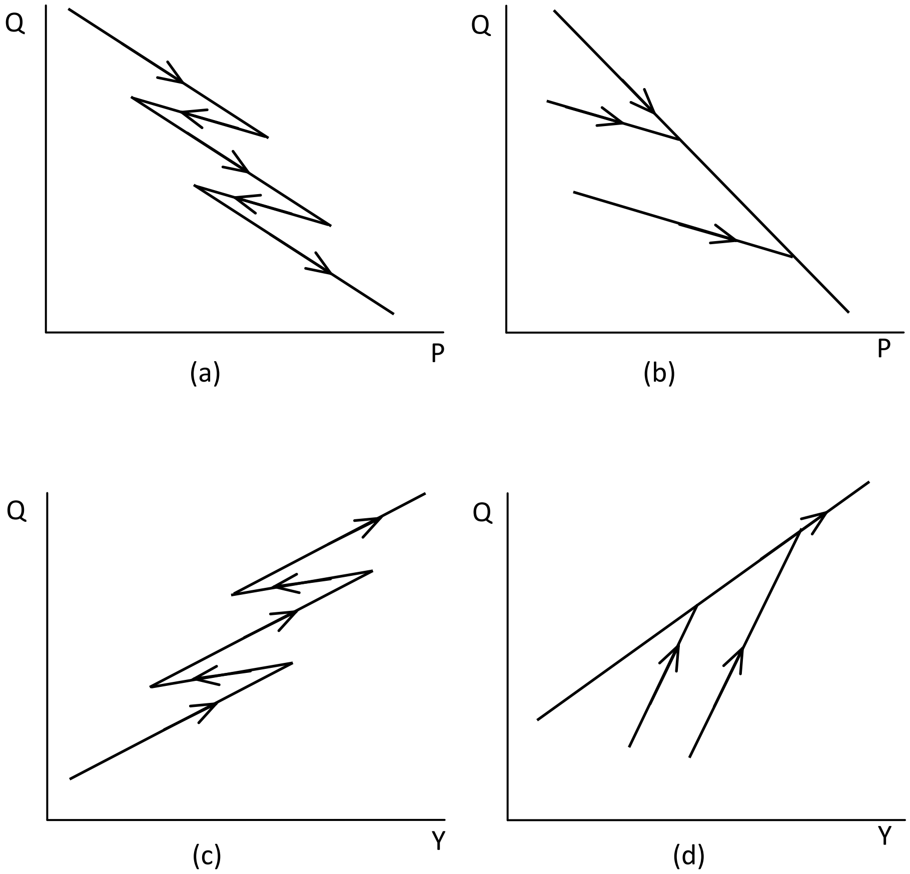
The paper is organized as follows. Section 2 reviews the literature on reversible and asymmetric responses, their importance in practice and sets the context for air travel. Section 3 describes the data and econometric model to decipher the potential imperfect reversibility for air transport demand. Section 4 presents the findings while section 5 concludes.

2. Reversibility, Asymmetry, Hysteresis

Perfect reversibility of demand or symmetry in demand responses means that the demand response to an increase in one of the driving factors (e.g. price or income) is exactly of the same magnitude and of opposite direction as the response to an equal reduction in the same factor. Therefore, for a perfectly reversible price effect, demand reductions during an increase in prices will be fully compensated by demand increases during similar price falls (or vice versa). In a natural experiment, this full recovery in consumption was not realized for petrol consumption in most of the developed world during the 1970's oil price increases and subsequent falls. This observation gave rise to a sustained academic interest in imperfect price reversibility or asymmetry in price elasticities of petrol and oil demand in the 1990s. Although such imperfect reversibility was previously discussed and empirically investigated by Wolffurm (1971) as early as the 1970s for agricultural supply, Gately (1992) and Dargay (1992) were the first to empirically investigate the issue for petrol consumption from motor vehicles in the USA and UK respectively. Their work was further enhanced by subsequent research in the areas of non-transport fuel demand (Dargay and Gately 1995, Ryan and Plourde 2002), total fuel demand, industrial energy demand (Adeyemi et al. 2007, 2010), vehicle miles travelled (Gately 1992) etc. for different geographic regions and countries (e.g. Dargay 1992 for the UK, Gately 1992 for the USA, Dargay and Gately 1997 and Adeyemi et al. 2010 for OECD, Sentenac-Chemin 2010 for India). There were also evidence of such price asymmetry in demand for telephone calls (Bidwell et al. 1995) and cigarettes (Young 1983).

In addition to the notion of reversibility with respect to rising and falling prices, a second type of reversibility was identified by Gately (1992) for demand for petrol and vehicle miles travelled. Gately (1992) argued that the demand response to price increases could be different depending on price history - more precisely on whether the current price is above or below a previous maximum. Young (1983) also made similar arguments for cigarette demand, but based on the relationship of current price with previous minimum price. This second type of imperfect reversibility is known as hysteresis. Gately (1992) and Young (1983) both found an evidence of hysteresis and the majority of the studies mentioned above utilize a formulation to investigate both types of imperfections. The two types of reversibility with respect to fuel price and income are explained in Fig. 1. The two types of reversibility with respect to fuel price and income are explained in Fig. 1. Panels (a) and (c) show asymmetry in demand responses, where the demand curve has different slopes during price rises and price falls. Panels (b) and (d) show the changes in slopes beyond certain points as a result of hysteresis. All of the aforementioned studies focused on the effects of price on demand and found evidence of at least one type of imperfect price-reversibility.

Similar to the effects of price, income also can have an asymmetric effect on demand. In the transport area, Goodwin (1977) was the first to mention that habit and established practices can result in an irreversible or imperfectly reversible behaviour for mode choice, although empirical evidence on imperfect income-reversibility is rather sparse in the transport and energy domain. Pendyala et al. (1995) and Dargay (2001) found evidence of an asymmetric effect of income on car ownership in the USA and UK respectively, while Gately and Huntington (2002) report asymmetric income effect on oil consumption. However, more recently Hauksdottir (2010) did not find any evidence of income asymmetry in petrol demand in Iceland.



(a) (b) (c) (d)

Fig. 1 Hypothetical demand shapes for (a) price asymmetry, (b) price hysteresis, (c) income asymmetry and (d) income hysteresis. Q=quantity, P=price, Y=income.

The imperfect reversibility or irreversibility of demand with respect to price and income has important consequences. Dargay and Gately (1997) and Gately and Huntington (2002) find that ignoring the asymmetric effects of price or income not only biases the elasticity estimates for that particular variable but also for other variables, the extent of the bias being contingent on the correlation among the explanatory factors. This would mean that the demand forecasts from a reversible model could also be biased and therefore could mislead policy formulation or infrastructure and operational planning. Given such importance of asymmetric responses in demand modelling, it is somewhat surprising that aviation demand models have not incorporated this issue so far. A brief review of 14 recent studies on air transport demand as described in Wadud (2013) reveals that all of these have the underlying assumption of perfect reversibility of demand in response to the changes in the demand drivers. Transportation Research Board's synthesis on aviation activity forecasting also does not address the issue of imperfect reversibility in demand models (Spitz and Golaszewski 2007), while the most recent report by the UK's Airports Commission (2013) also does not mention the potential asymmetry and hysteresis effects.

There are reasons as to why air transport demand could show asymmetry with respect to income or fuel prices. Although the classical demand theory does not differentiate between the impacts of price increases and decreases, applied researchers have speculated that consumers react more to price increases than to reductions simply due to inherent behavioural reasons. There is empirical literature on such behavioural asymmetric response of consumers to increasing and decreasing product prices, see for example Bidwell et al. (1995) for telephone calls or Young (1983) for cigarette smoking. At the same time, there is evidence of a quicker and larger cost pass-through to product prices by businesses during rising product costs than during falling costs, a phenomenon often known as 'rocket and feather' responses (product price shoots up like a rocket during cost increases, but falls like a feather during cost reductions, see Bacon 1991). Escobari (2013) and Ozmen (2009) have recently investigated such asymmetric cost pass-through in the airline industry, with Ozmen (2009) specifically focusing on fuel cost pass-through. Since fuel prices are a large share of airlines' operational costs, it is likely that ticket prices would show an asymmetric change to fuel price increases and reductions. Therefore, hypothetically, even if the consumers were symmetric in their price response, since ticket prices change asymmetrically to fuel price changes, final demand response would still be asymmetric with respect to fuel price changes. In practice, both of these effects would likely be in action.

The asymmetry in cost pass-through could also depend on whether the price increases are large or not. While small changes in fuel price can possibly be cushioned by improving operational efficiencies, steep rises in fuel prices, especially rises above a previous maximum price, inevitably show up through ticket price mark-ups. For fuel price increases above a previous maximum, ticket mark-ups could be larger than the cost pass-through due to smaller, sub-maximum increases in price. Also such large increases above a previous maximum price can lead to permanent modal shift from some air travellers. This would be an example of the second type of imperfect reversibility (hysteresis) in the price effects on air transport demand. Note that neither type of imperfect price-reversibility has been studied before for air travel.

Similarly, there could be some 'stickiness' in income responses. Passengers may switch to air travel as soon as income rises, yet, a fall in income may not bring about the same reduction in air travel as the traveller may have become accustomed to the new mode by then. While such a hypothesis appears to hold for car ownership and car travel (e.g. Dargay 2001), it is still not clear if it would hold true for aviation. The effects of increasing income above and below a previous maximum income could also be different. During an income rise from below a previous maximum income may encourage the traveller to be confident about future increases in income and to quickly attain his/her previous level of air travel. This would mean income elasticity for sub-maximum income increases will be larger than the elasticities for income rises above a previous maximum. On the other hand, it is also not implausible that travellers would be more cautious during a sub-maximum income increase due to the experience of a fall in income previously. Given the lack of a theoretical underpinning for these plausible responses, it is important to empirically investigate the potentially asymmetric or imperfectly reversible impacts of income.

3. Data and Methods

In order to investigate the potential asymmetry and imperfect reversibility hypothesis in this paper, we choose revenue passenger miles (RPM) flown as the metric for air travel demand in the USA. The data is collected for the US carriers from the Bureau of Transport Statistics (2013), with temporal coverage from 1978 to mid-2013. This time period includes not only the large fuel price increases of the second oil shock, but also the recent price rises since 2005 and the sustained recessions around 2008-2009. Jet fuel (kerosene type) prices were collected from Energy Information Administration (2013) and converted to real prices using Bureau of Labor Statistics' (2013) consumer price indices. Income is represented by monthly real disposable income from National Income and Product Account of the Bureau of Economic Analysis (2013). Population is from the same source as well. Fig. 2 presents the evolution of RPM and RPM per capita per day in the USA. As expected, the growth effect is tampered for the per capita normalized series.

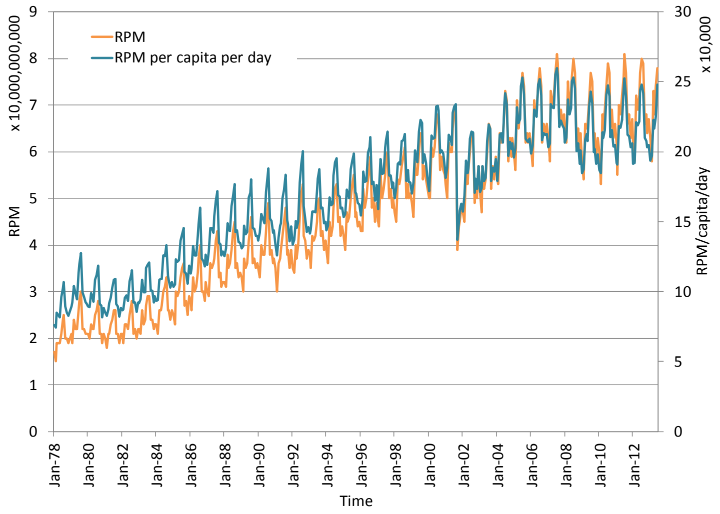


Fig. 2 Evolution of RPM and RPM per capita per day

In a traditional econometric demand model, income and fuel price - the two important demand drivers that is of interest here - enter the model specification directly as they are, generally in a logarithmic form. This specification inherently has the assumption of perfect reversibility as positive and negative or small and large changes in the demand drivers are treated as having the same impact on demand. In order to understand imperfect reversibility, we need to differentiate between the demand responses to a positive and a negative change, or between a sub-maximum price (or income) recovery and a maximum price (or income) increase. We achieve that following the technique of variable decomposition proposed by Wolffram (1971). Wolffram (1971) proposed to decompose the price series into two components: a monotonically decreasing series of price falls and a monotonically increasing series of price rises. However, this decomposition for prices could only differentiate between the first type of imperfect reversibility, i.e. differences in the effects between rising and falling prices. Gately (1992) and Dargay's (1992) improved price decomposition techniques could also detect the second type of imperfect reversibility or hysteresis effects and have become the standard in the transport and energy asymmetry literature. We therefore follow their decomposition technique here.

We decompose each of our price and income variables, both in logarithms, into three component series as follows:

$$V_t^{max} = max(V_0, \ldots., V_t) \tag{1}$$

$$V_t^{rec} = \sum_{i=0}^{t} max\{0, (V_{i-1}^{max} - V_{i-1}) - (V_i^{max} - V_i)\} \tag{2}$$

$$V_t^{cut} = \sum_{i=0}^{t} min\{0, (V_{i-1}^{max} - V_{i-1}) - (V_i^{max} - V_i)\} \tag{3}$$

V_t^{max} refers to the maximum value of the variable of interest (price or income, in logarithms) up to the time t. This is monotonically increasing and changes only if the variable in time t is larger than the maximum value at time t-1. V_t^{cut} refers to the cumulative series of the falls in the value of the variable, this is monotonically decreasing, and is always negative. V_t^{rec} refers to the cumulative recovery of the value of the variable, when it is below V_t^{max}. Therefore it represents the sub-maximum cumulative rises in the variable, and is again monotonically increasing only. In order for the first type of imperfect reversibility, or asymmetry, to hold with respect to the variable, the parameter estimates for V_t^{cut} and V_t^{rec} should be different. On the other hand, for the second type of imperfect reversibility to hold, parameters related to V_t^{max} and V_t^{rec} should be different.

Our econometric model for air transport demand is a reduced form one. Dependent variable is RPM per capita per day (RPM^{cd}).[1] By converting to per capita, we control for the increases in RPM with increases in the population. Per day conversion controls against the variations in RPM for the different number of days in the months (including leap years) so that genuine monthly variations can be deciphered. We also run a second model using RPM per capita (RPM^{c}) as the dependent variable. The two explanatory factors, and also the variables of our interest for their potential imperfect reversibility impacts, are disposable income per capita (Y) and kerosene type jet fuel price (P). Both of these variables enter the specification in their decomposed forms, as described above and plotted in Figs. 3 and 4. Following Ito and Lee (2005) we also include monthly unemployment rate as an explanatory factor in our model. In addition to these continuous variables, we include several dummy variables in order to control for external events. These include the air controllers strike in 1981 which resulted in the mass discharge of air controllers, first gulf war in 1991, the 9-11 terrorist attack in 2001, the Iraq war in 2003, the SARS scare of 2003. Given the SARS scare and Iraq war had overlaps, we include one dummy variable to represent both. The 9-11 terrorist attack in the USA had a profound effect on the aviation industry and air transport demand in the USA. We include one dummy variable for September 2001 to represent the sudden dip in passenger patronage in that month. In addition, the event led to various other security measures, which made air travel quite unpleasant, and may have led to a sustained impact, at least for a few years (Ito and Lee 2005). Therefore we add a dummy variable which attains a value of 1 for three years after September 2001,

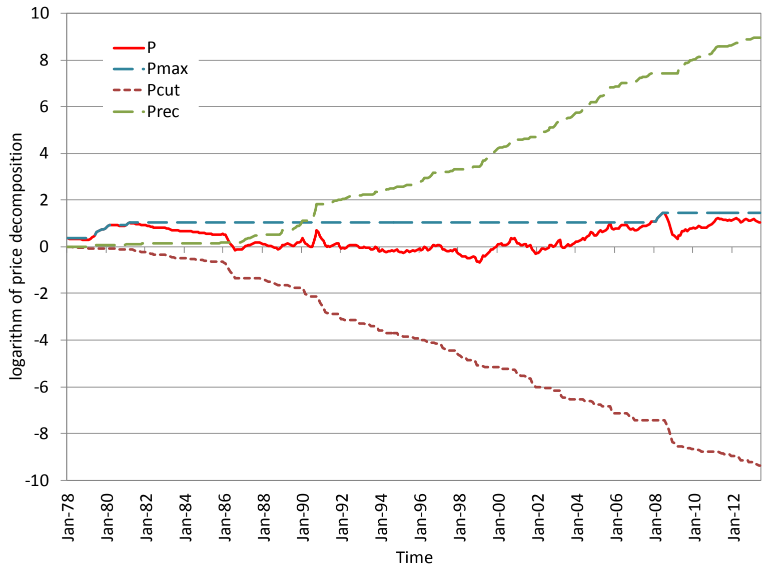


Fig. 3 Evolution of logarithm of real fuel price and its three decompositions

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[1] This avoids the inclusion of population as a dependent variable, which can be problematic because of its high correlation with income.

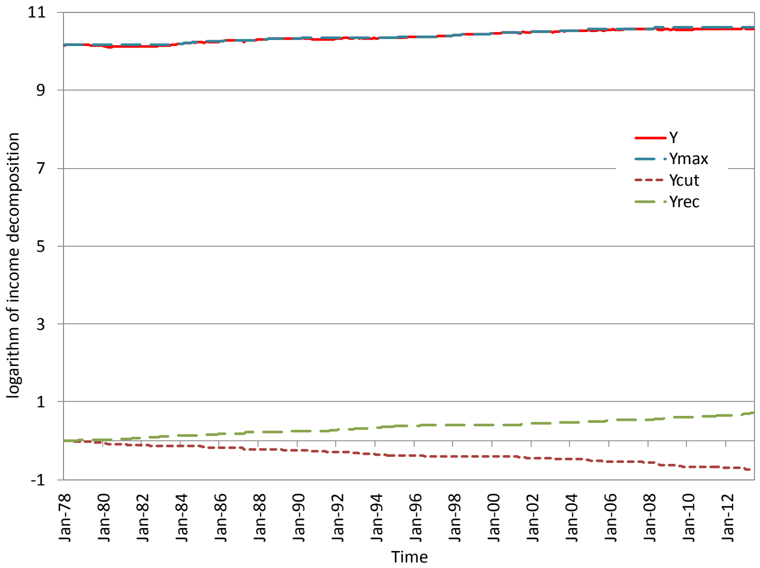

Fig. 4 Evolution of logarithm of real per capita disposable income and its three decompositions

and 0 otherwise.[2] In addition, we add a dummy variable for the December months for those years when the thanksgiving weekend falls in the December, so that the additional air travel can be explained. We also control for the deregulation of the airlines in 1978, by adding a dummy for the pre-regulation months. All of these variables are explained in Table 1.

Table 1. Variable description and descriptive statistics

Notation	Description
RPM^{cd}	Log (Revenue Passenger Miles per capita, per day)
RPM^{c}	Log (Revenue Passenger Miles per capita), a different metric
Y^{max}	Log (Real disposable income per capita, maximum series)
Y^{rec}	Log (Real disposable income per capita, cumulative recovery series)
Y^{cut}	Log (Real disposable income per capita, cumulative fall series)
P^{max}	Log (Real fuel price, maximum series)
P^{rec}	Log (Real fuel price, cumulative recovery series)
P^{cut}	Log (Real fuel price, cumulative fall series)
U	Log (Unemployment rate)
$(DinM)$	Log (Number of days in a month), optional, when RPM^{c} used
D_1	Dummy for pre-deregulation of 1978 lagged 3 months, January 1978-January 1979*
D_2	Dummy for air controllers' strike in October 1981
D_3	Dummy for the first Gulf War, August 1990 to March 1991
D_4	Dummy for Iraq War and SARS, February to July 2003
D_5	Dummy for 9-11, September 2001
D_6	Dummy for the subsequent effects of 9-11, October 2011-2014
D_7	Dummy if the thanksgiving weekend falls in December
MD_k	Monthly dummies

* We assume that the effects of the airline deregulation act would not be instantaneous after the signing in October, 1978. 6 months lag showed similar results.

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[2] We have also used alternate time periods of 2 and 4 years. 3 years produced best regression results.

Given the nature of the decomposition of the variables, they are non-stationary (monotonically increasing or decreasing). While regressions with non-stationary variables are generally spurious, Engle and Granger (1987) show that there could be a combination of the non-stationary variables that is stationary. In such cases the variables are said to be cointegrated, and there exists a valid long run relationship between them. The Ordinary Least Squares (OLS) residuals for the regression of the cointegrated variables will also be stationary, and the unit root test for these residuals acts as a test for cointegration as well. The use of monthly data in this study raises the possibility of seasonal unit roots, however this may not be an important consideration for multivariate regression. Firstly, the tests for seasonal unit roots (e.g. the HEGY test by Hylleberg et al. 1990) are known to have a low power, thus often accepting the seasonal unit root hypothesis making the tests somewhat unreliable. Secondly, Osborn (1993) argues that unless there are good economic rationalizations for seasonal unit roots then one need not worry about them and seasonal non-stationarity can often be adequately represented by seasonal (here monthly) dummies. In order to control for the potential seasonal differences in air transport demand, we therefore add 11 dummy variables for the months of February through December.

Engle and Granger (1987) suggested that the OLS estimate of a static equation involving the cointegrating variables will be valid for the long-run relationship of the non-stationary variables (and stationary, if any) and it is a widely used technique in time-series multivariate econometrics. However, Hendry (1986) and Phillips and Loretan (1991) argued that such OLS estimation from the static models can leave substantial autocorrelation in the residuals, and thus the inference on the parameter estimates can be misleading. Therefore, Banerjee et al. (1986) suggest that the long run parameters should be determined from a dynamic model. As long as the dynamics are specified such that the residuals are not autocorrelated, then the inference on the parameter estimates are valid, provided a long-run cointegrating relationship exists (Patterson 2000). We therefore follow a dynamic stock adjustment modelling approach in this study, whereby the lags of the dependent variable are added as an explanatory factor. We then test if the 'implied' long-run relationship from the dynamic model is spurious or not.

The final specification of the passenger air travel demand model is as follows, where the variable notations and descriptions are presented in Table 1:

$$RPM_t^{cd} = \mu + \alpha_{max} Y_t^{max} + \alpha_{rec} Y_t^{rec} + \alpha_{cut} Y_t^{cut} + \beta_{max} P_t^{max} + \beta_{rec} P_t^{rec} + \beta_{cut} P_t^{cut} + \kappa U_t + \sum_{j=1}^{7} \lambda_j D_{jt} + \sum_{k=2}^{12} \varphi_k MD_{kt} + \sum_{i=1}^{l} \gamma_i RPM_{t-i}^{cd} + (\delta DinM_t) + \varepsilon_t \qquad (4)$$

Given the aviation RPM does not have a direct causal effect on income, price of oil or unemployment, we infer that the right side variables are all exogenous. The continuous variables (RPM, price, income and unemployment series) are all expressed in logarithms and as such Eq. (4) is the widely used Cobb-Douglas constant elasticity specification, where the parameter estimates directly provide the elasticities of RPM with respect to the corresponding variables. Note that the perfectly reversible model is a special case of the imperfectly reversible model in Eq. (4). For a perfectly reversible response to income, $\alpha_{max}=\alpha_{rec}=\alpha_{cut}$, while for perfectly reversible price effects $\beta_{max}=\beta_{rec}=\beta_{cut}$. Therefore these tests for equality of the parameters also act as a test for the choice between the perfectly and imperfectly reversible models.

4. Results and Discussions

Table 2 presents the estimation results for two of the metrics for air travel demand in the USA. Because of the monthly nature of our data and strong correlation between the variables at annual interval, we add a 12th lag of the dependent variable in both the models. We then test for the addition of lags 1, 2 and so forth, and find that lags 1 and 12 can provide a parsimonious model with no autocorrelation in the residuals for both models. We employed AIC and BIC for model fit, Engle's Langrange Multiplier test for ARCH effects (1982), Breusch-Godfrey LM test (Breusch 1978, Godfrey 1978) and Durbin's alternate h-test (Durbin 1970) for residual autocorrelation. We also calculate the 'implied' long-run parameters of all the variables, which gives us an 'implied' cointegration vector as per Patterson (2000), and then test if the residuals are stationary through Dicky-Fuller's GLS test (1979) for a unit root. The residuals were stationary for both the models, ensuring that the long run relationship between the variables as implied by the dynamic model is not spurious. As per our earlier discussion, inference is based on the dynamic models of Table 2.

Monthly dummies are significant for most months, indicating the seasonality in air travel demand.[3] The negative and statistically significant estimate for pre-deregulation dummy (D_1) indicates that air travel increased post-deregulation. The changes in demand due to air traffic controllers' strike and subsequent mass-firing (D_2) is not statistically significant. Gulf war dummy (D_3) is statistically insignificant, a result similar to Ito and Lee (2005). Estimate for the dummy for the Iraq war and SARS (D_4) is statistically insignificant too. The effect of the 9-11 event on aviation activities in September 2001 is clearly evident through the large and statistically significant parameter estimate for (D_5). The persistently negative effect of 9-11 is evident through the statistically significant negative estimate for D_6. During the years when thanksgiving weekend falls in December (D_7), demand is larger than

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[3] We have also estimated a model with an interaction of monthly dummies with year in order to account for the possibility of increasing seasonal variance with time, but that model fell marginally short in ARCH test. Parameter estimates of this model lead to similar conclusions.

when they are contained entirely in November. All of these results are 'as expected'. Given the results of Models 1 and 2 are very similar, the following discussion is based on Model 1 results.

Table 2. Parameter estimates for the econometric model

	Model 1 (RPM^{cd})		*Model 2 (RPM^{c})*	
	parameter	t-stat	parameter	t-stat
RPM lag 1	0.643***	20.61	0.636***	20.62
RPM lag 12	0.175***	6.71	0.172***	6.59
Y^{max}	0.307***	4.11	0.330***	4.42
Y^{rec}	0.638***	5.51	0.627***	5.38
Y^{cut}	0.383***	2.86	0.356***	2.64
P^{max}	-0.093***	-4.44	-0.100***	-4.8
P^{rec}	-0.010**	-2.09	-0.011**	-2.47
P^{cut}	0.002	0.23	0.001	0.1
U	0.011	0.88	0.011	0.94
$(DinM)$			1.296***	4.63
D_1	-0.041***	-3.21	-0.044***	-3.45
D_2	-0.022	-0.85	-0.021	-0.81
D_3	-0.011	-1.09	-0.009	-0.93
D_4	-0.015	-1.28	-0.012	-1.08
D_5	-0.366***	-14.16	-0.366***	-14.18
D_6	-0.020***	-2.99	-0.022***	-3.27
D_7	0.064***	4.74	0.064	4.74
MD_2 -Feb	0.050***	8.01	0.093***	3.49
MD_3 -Mar	0.132***	18.72	0.191***	22.95
MD_4 -Apr	0.041***	5.95	0.057***	5.01
MD_5 -May	0.050***	7.66	0.072***	11.09
MD_6 -Jun	0.149***	18.46	0.165***	13.82
MD_7 -Jul	0.100***	10.64	0.123***	13.58
MD_8 -Aug	0.090***	9.05	0.093***	9.32
MD_9 -Sep	-0.068***	-7.53	-0.051***	-3.93
MD_{10} -Oct	0.050***	7.93	0.071***	11.25
MD_{11} -Nov	0.009	1.5	0.025**	2.25
MD_{12} -Dec	0.049***	7.7	0.070***	10.53
Constant (μ)	-1.636***	-2.5	-5.573***	-4.69
<u>*Diagnostic tests*</u>				
N	426		426	
Adj-R^2	0.993		0.993	
AIC/BIC	-1898.6/-1785.1		-1897.3/-1779.7	
Dicky-Fuller GLS unit root test for stationarity of long run relationship	-3.17 ($p<0.05$)		-3.11 ($p<0.05$)	
Breusch-Godfrey test for autocorrelation	2.04 ($p=0.15$)		2.43 ($p=0.12$)	
Durbin's h test for autocorrelation	1.91 ($p=0.17$)		2.27 ($p=0.13$)	
Engle's LM test for ARCH effects	2.11 ($p=0.15$)		1.95 ($p=0.16$)	

The three parameters related to Y^{max}, Y^{rec}, and Y^{cut} have values of 0.307, 0.638, and 0.383 respectively, with all being statistically significant at 99% confidence level. These represent the short run elasticities, the corresponding long run elasticities are 1.684, 3.503 and 2.102 (Table 3). As mentioned earlier, a test for the equality of these parameters, i.e. $\alpha_{max}=\alpha_{rec}=\alpha_{cut}$, acts as a test for the reversibility hypothesis as well. Wald test for the equality of these parameters has an F-statistic of 8.86 and a p-value of 0.00 (Table 4), which means that we can clearly reject the equality restriction. Therefore the income reversibility hypothesis for air travel demand is not justified. Test of equality for $\alpha_{rec}=\alpha_{cut}$ results in an F-statistic of 10.9 (p=0.00), indicating that the asymmetric effect for sub-maximum income rises and falls also exists. However, for a fall in income and rise in income above a previous maximum ($\alpha_{max}=\alpha_{cut}$), the asymmetry cannot be established (F=0.24, p=0.62). Therefore, we can conclude that generally there is a symmetric effect for income rises and falls as long as the income rise is above a previous maximum. All of these findings on the equality of the parameters are similar for the long run parameters too since we have a single adjustment process for all variables as per Dargay and Gately (1997).

Table 3. Short-run and long run demand elasticities with respect to price and income (Model 1)

	Short-run	Long-run#
Y^{max}	0.307***	1.684***
Y^{rec}	0.638***	3.503***
Y^{cut}	0.383***	2.102***
P^{max}	-0.093***	-0.510***
P^{rec}	-0.010**	-0.052**
P^{cut}	insig.	insig.

#long run parameter = $(\alpha$'s or β's$)/(1-\gamma_1-\gamma_{12})$ from Eq. (4)

Table 4. Hypothesis tests for imperfect reversibility (Model 1)

Test restrictions	F-statistic	p-value
$\alpha_{max} = \alpha_{rec} = \alpha_{cut}$	8.86	0.00
$\alpha_{rec} = \alpha_{cut}$	10.9	0.00
$\alpha_{max} = \alpha_{cut}$	0.24	0.62
$\alpha_{max} = \alpha_{rec}$	6.38	0.01
$\beta_{max} = \beta_{rec} = \beta_{cut}$	8.02	0.00
$\beta_{max} = \beta_{cut}$	15.78	0.00
$\beta_{rec} = \beta_{cut}$	5.28	0.02
$\beta_{max} = \beta_{rec}$	16.01	0.00

In order to determine the presence of the second type of imperfect reversibility or hysteresis, which suggests that the effect of rising income could be different depending on the level of previous income, we test for the equality $\alpha_{max}=\alpha_{rec}$. This hypothesis is also rejected clearly with an F-statistic of 6.38, and a corresponding p-value of 0.01. Therefore it appears that, when income increases following a previous fall in income, people increase their air travel consumption more rapidly in comparison to absolute increases in income. Both Boeing (2013) and Airbus (2013), the two largest

airframe manufacturers, independently concluded that air transport demand is resilient to shocks and generally recovers quickly after a shock, which lends anecdotal evidence to our finding.
The results on the impact of fuel price on RPM also provide important insights. Equality test of the parameters for the three price series, i.e. $\beta_{max}=\beta_{rec}=\beta_{cut}$, has an F-statistic of 8.02, with a p-value of 0.00, thus rejecting the hypothesis of a perfectly reversible price effect. It is evident from the estimate of β_{cut} that the falling price has no statistically significant impact on the demand, while estimates for both the price rise series are statistically significant. Because of the statistically insignificant estimate of β_{cut}, pair wise equality tests of $\beta_{max}=\beta_{cut}$ and $\beta_{rec}=\beta_{cut}$ reveal that the sensitivity to price cuts is statistically different from the two price rise series (F=15.78 and 5.28 respectively). The insignificant parameter estimate for β_{cut} is not surprising though. Recall that the final demand asymmetry can arise not only due to consumer's (potentially) inherent asymmetric behavioural patterns but also due to the airlines' asymmetric cost pass-through of fuel price to ticket prices. Given previous evidence of asymmetric cost pass-through in the airline industry, it is likely that fuel price cuts do not show up on ticket prices immediately or in proportion to the price cuts, as it does for fuel price rises. As such, there is no or much smaller reductions in ticket prices for the travellers to respond to, and hence the insignificant response to fuel price cuts.

Short run elasticities with respect to maximum price and price recovery are 0.093 and 0.010 and the long run elasticities are 0.51 and 0.05 respectively. Wald test for equality of β_{max} and β_{rec} has an F-statistic of 16.01 with a p-value of 0.00, indicating a statistically significant difference. Results confirm the presence of hysteresis type of imperfect reversibility: the effect of increases in fuel price on air travel demand depends on the previous price history. Especially, demand reductions are stronger for price increases above the previous maximum price. A long run fuel price elasticity of 0.51 for prices above a previous maximum is substantial. Also, the effect of price recovery on demand, although statistically significant, is numerically fairly small (0.05 even in the long run), indicating little impact of fuel price rise on air travel demand if the price remain below the previous maximum. Such hysteresis effects have previously been observed for petrol demand as well (Gately 1992, Dargay and Gately 1997). Note that the ticket price faced by the consumers due to fuel price changes are different as the ticket price changes depend not only upon the fuel costs but also due to the cost pass-through and fuel price hedging. As such consumer responses to direct ticket price changes would most likely be different from the fuel price elasticities.

The approach of testing the equality of the decomposed income and price series offers insight on the comparative assessment of those parameters in the given model, but cannot tell us if this model is better at explaining the temporal variations in air travel demand than a perfectly reversible model.

In order to independently compare our results with alternate models of perfect reversibility/ symmetry and Wolfram's (1971) specification, we run two further models with RPM^{cd} as the dependent variable (since model 1 is our preferred model from Table 2). The parameter estimates for our variables of interest and diagnostic test results are presented in Table 5. The adjusted R^2 of all three models are similar, however, Model 1 has the smallest AIC and BIC of the three models, indicating its superiority over the alternate specifications.

Table 5. Comparison of reversible and imperfectly reversible models

	Model 1		Model 3		Model 4	
	Imperfectly reversible, asymmetry + hysteresis		Perfectly reversible		Imperfectly reversible, asymmetry only	
	Short run	Long run	Short run	Long run	Short run	Long run
Y^{max}	0.307***	1.684***				
Y^{rec}	0.638***	3.503***				
Y^{rise}					0.327***	1.803***
Y^{cut}	0.383***	2.102***			0.251***	1.381**
Y			0.308***	1.821***		
P^{max}	-0.093***	-0.510***				
P^{rec}	-0.010**	-0.052**				
P^{rise}					-0.016***	-0.089***
P^{cut}	0.002	0.009			-0.011*	-0.063*
P			-0.017***	-0.099***		
<u>*Goodness of fit*</u>						
Adj. R^2	0.993		0.993		0.993	
AIC/BIC	-1898.6/-1785.1		-1879.3/-1782.0		-1877.0/-1771.6	
<u>*Hypothesis test*</u>						
$\alpha_{rise} = \alpha_{cut}$					F=1.34 (p=0.25)	
$\beta_{rise} = \beta_{cut}$					F=1.44 (p=0.23)	

A comparison of our imperfectly reversible model, Model 1, with the reversible model, Model 3, shows that the income elasticity from the two models do not differ significantly, when using the income increases above previous maximums for Model 1. Since the demand forecast models are generally based on a forecast of a continuously rising future income, it appears that the forecasts based on income from the reversible model may not be substantially biased. However, whether this is a generic finding, or is specific to this US dataset remains to be investigated. The principal advantage of using the imperfectly reversible model will be for demand projections following a recession. Given the hysteresis effect of income and the resulting larger elasticity during income recovery, using the single income elasticity from the perfectly reversible model would underestimate demand forecasts by at least a factor of two. Therefore operational planning during the recovery phase after a recession should make use of the imperfect reversibility model results.

The differences between the estimates for price elasticities are more visible. The reversible model shows a price elasticity of 0.017 (~0.1 in the long-run), while the elasticity with respect to price increases above previous maximums from our imperfectly irreversible model is 0.093 (0.51 in the long-run), which is more than five times larger. Elasticity with respect to price recovery is 0.01 which is smaller than the reversible elasticity estimate. The difference in the price elasticities has important policy implications. It indicates that the effect of any potential taxation policy that increases fuel prices marginally (i.e. sub-maximum) would be overestimated if the price elasticity from the reversible model are used. On the other hand, effects of a tax that raises fuel prices above the previous maximum will be underestimated if the perfectly reversible model results are used.

Model 4, which follows Wolfrram's (1971) decomposition of the variables into two component series, allows only asymmetry between rising and falling prices or incomes and does not consider prior history of the variables. In Model 4, the rising series is computed by: $V_t^{rise} = V_t^{max} + V_t^{rec}$ where V_t^{max} and V_t^{rec} are the same as in Eqs. (1)-(2). Model 4 indicates that the elasticities with respect to rising and falling prices or income are not statistically different from each other (F for income = 1.34, p=0.25; F for price = 1.44, p=0.23) and thus does not reject the reversibility hypothesis. However, we note that Model 4 has an inferior goodness of fit compared to Model 1 in terms of AIC and BIC. It is therefore important to include both the asymmetry and hysteresis effects in the econometric specification of the air transport demand model, as the omission of one can result in an incorrect conclusion about the other.

5. Conclusions

We argue in this paper that air transport demand does not show a reversible relationship with its demand drivers, as assumed in typical air transport demand and forecast models. We use econometric techniques using US data on Revenue Passenger Miles to provide evidence on imperfectly reversible demand responses to fuel price and income changes. There is clear evidence that elasticities with respect to increasing income or price are not the same as elasticities with respect to a reduction in those factors, which is an example of asymmetric demand response. As part of the demand asymmetry estimates, we find that fuel price cuts do not have any statistically significant impact on aviation demand. We also find that hysteresis effects, whereby the elasticities depend on previous history, are also present for income and fuel price. In particular, income elasticity during a rising income is larger if income remains below a previous maximum than if income is above the previous maximum. For price effects, the opposite happens: response to an increase in price above a previous maximum is substantially larger than to an increase in price below a previous maximum. In fact, the fuel price elasticity of air transport demand is very small in magnitude for price recoveries below a previous maximum price.

Hysteresis in the income effects of air transport demand implies that during the recovery phase after an economic recession, air travel demand is expected to grow quicker than predicted by the reversible demand models. This could be important for short term planning and operations including optimization of airlines' revenue management, especially after a recession. The longer term implications for demand projection, at least for our dataset, do not appear substantially biased although there is a possibility of some overestimation. The presence of hysteresis in the price effects indicates that the impact of any taxation policy implemented to increase fuel prices will depend disproportionately on the resulting fuel price from the tax additions. A taxation structure that raises the fuel price above the previous maximum would have a substantially larger effect than one that leaves the increased fuel price still below a previous maximum. Hysteresis in price effects can also be important for airlines' short term operational planning and pricing strategy. In addition, we find that ignoring the effects of hysteresis in the imperfectly reversible model can bias the findings on price or income asymmetry.

A few questions remain to be answered. We cannot detect if the asymmetry in the fuel price response is due to behavioural reasons, or because of asymmetric fuel cost pass-through by the airlines, or both. This has implications for demand responses to changes in ticket prices and subsequent effects of policy or other business decisions. We conjecture, if the asymmetric response to fuel price is due to behavioural factors, then the asymmetry will likely hold and possibly amplify for ticket prices as well. On the other hand if the asymmetric cost-pass through is the major reason, then any asymmetric response for ticket prices will likely be small. Further empirical investigation into the mechanism of asymmetry and hysteresis in air transport demand will therefore be useful.

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