HOW TO FLY WITHOUT KEROSENE?

T. Hahn, S. Hittel, R. Klophaus*, J. Mertens, M. Ziegler

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Abstract

This exploratory research aims to investigate the relationship between soaring fuel prices and future air traffic. We argue that an industry relying on fossil fuels cannot maintain unconstrained growth rates in the long run. The paper analyzes the short-term impact of higher fuel prices on airline operating costs, passenger fares and demand for short-haul and long-haul services. Our results indicate that services offered by low-cost carriers and long-haul services are most adversely affected. We also contend that a strong increase in fuel prices may soon outweigh the potential impact of emission trading systems for the aviation industry. Finally, looking beyond the peak in oil production the paper gives a brief overview of the pros and cons of potential alternative fuels to kerosene.

Keywords: peak oil, future of aviation, fuel surcharges, airline demand, alternative fuels

1 INTRODUCTION

The aviation industry is probably the economic sector most depending on fossil fuels besides the petrochemical industry itself. Today, commercial aviation is characterized by growing passenger numbers and cargo volumes as well as expanding airport and airline capacities. According to a recent Airports Council International (ACI) forecast the current number of 4.5 billion passengers worldwide is expected to reach 9 billion by 2025.[1] Similar forecasts of air traffic growth are issued by manufacturers of commercial jetliners like Airbus and Boeing and proliferated by other sources including public

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* Corresponding author:
Centre for Aviation Law and Business, Trier University of Applied Sciences
Umwelt-Campus Birkenfeld , D-55768 Neubrücke, Germany
Phone: + 49 67 82 17 - 12 20, Fax: + 49 67 82 17 - 14 54
Mailto: klophaus@umwelt-campus.de

agencies and academia. Based on these forecasts on unconstrained air traffic growth the demand for kerosene is bound to grow.

The prospering world economy leads to a soaring demand for crude oil aside from aviation. OPEC projects a growth of oil demand from 84 million barrels per day (mb/d) in 2005 to 118 mb/d in 2030.[2] Therefore, demand is likely to exceed the production level of crude oil in the foreseeable future. By the time peak oil is reached and half of the global oil resources are exploited, costs for oil extraction will rise and keeping up the production level will become increasingly difficult. To our knowledge the impact of peak oil on commercial aviation has only recently been addressed by Kuhlmann[3] building upon peak oil theory associated with Marion K. Hubbert[4].

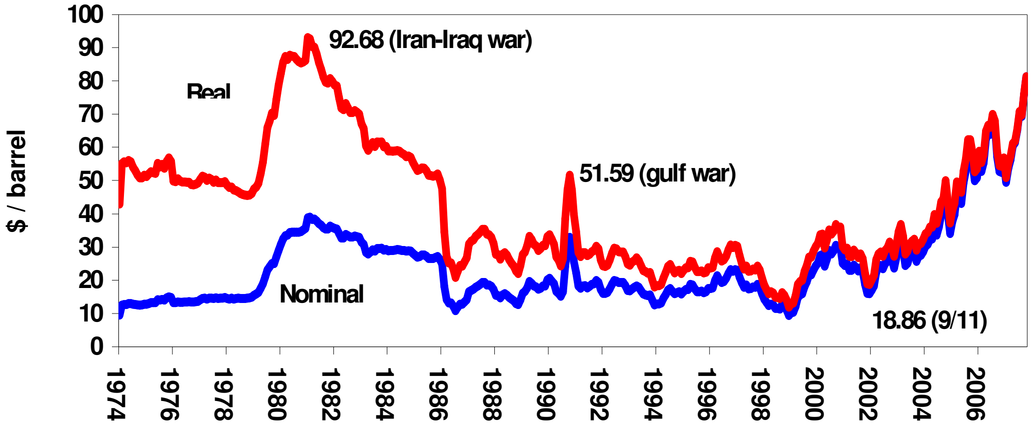
Our paper investigates the economic impact of higher kerosene prices in the short-term on fuel costs, the amount of surcharges on air fares and air passenger demand. The economic analysis of the short-term impact of increasing fuel prices on commercial aviation build upon the methodology developed for the analysis of the influence of environmental charges or the introduction of emission trading. Especially, our paper builds upon previous research on the impact of emission trading on aircraft operators recently published in a series of papers by Grimme, Scheelhaase and co-authors.[5]

The paper is structured as follows: Section 2 contains considerations on peak oil including an overview of predictions on the time of global oil production peak and forecasts for the future price of crude oil. Section 3 examines the short-term economic impact, i.e. assuming one-year horizon, of higher fuel prices on airline costs, ticket prices and passenger demand for short-haul and long-haul services. Short-haul is further differentiated into routes operated by full service network carriers (FSNCs) and low-cost carriers (LCCs). The results show that the rate of air traffic growth constrained by scarcity of kerosene are much lower - and may even be negative - than unconstrained air traffic growth, especially leading to a strong reduction of demand for leisure traffic and long-haul services. In the long run the aviation industry has to look beyond the fuel-efficient ‘3 liter aircraft’ and search for new groundbreaking ways to become less dependent on fossil fuels. Hence, Section 4 gives an overview of current research directions in the fields of future aircraft technology and the pros and cons of potential alternative fuels to kerosene. The closing Section 5 summarizes the paper’s results and concludes that peak oil has the potential to stop and even reverse long-term air traffic growth.

2 PEAK OIL AND FUTURE FUEL PRICES

End of October 2007, the spot price of Brent-Europe crude oil reached for the first time \$90 a barrel.[6] This reflects that world oil demand has continued to grow much faster than oil supply but also ongoing geopolitical risks, OECD inventory tightness, worldwide refining bottlenecks and speculative trading. \$90 a barrel is about 50 percent more than a year ago. In real terms, adjusted for inflation, oil is at its highest price since the early 1980s when it hit its peak following the Iranian Revolution and the beginning of the Iran-Iraq war (see Figure 1).

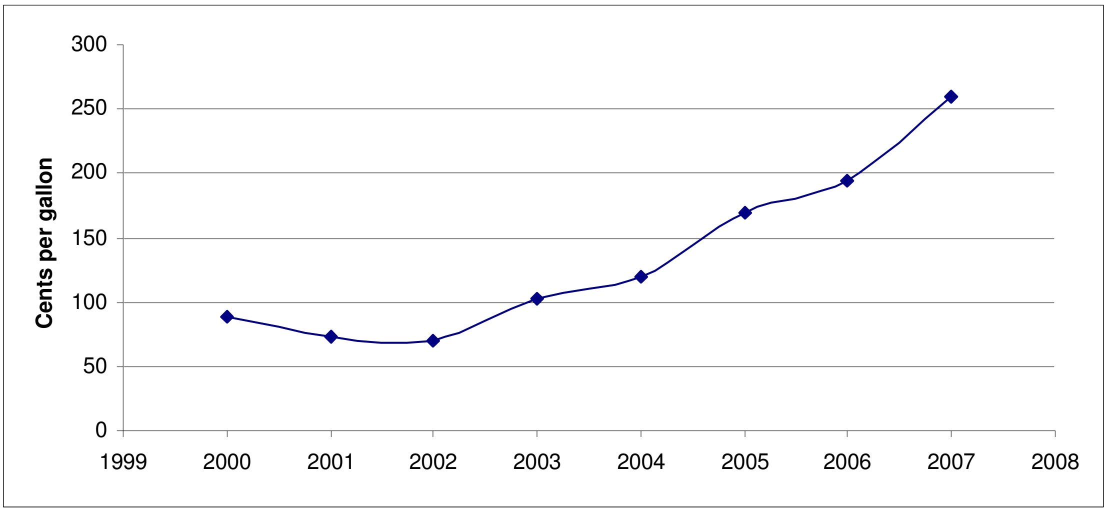
Figure 1: Real and nominal oil prices, 1974-2007 (real prices in 2007 dollars)



Source: EIA[7]

Kerosene is produced by distilling crude oil. Hence, the product price of kerosene is closely linked to crude oil prices. End of October the spot price for kerosene-type jet fuel in Rotterdam was about 260 cents a gallon (see Figure 2). This translates into close to \$110 a barrel. This spread of approx. \$20 on the spot price of Brent-Europe crude oil reflects the gross refining margin (costs and profits).

Figure 2: Kerosene-type jet fuel prices in Rotterdam, 1999-2007[8]



Source: EIA

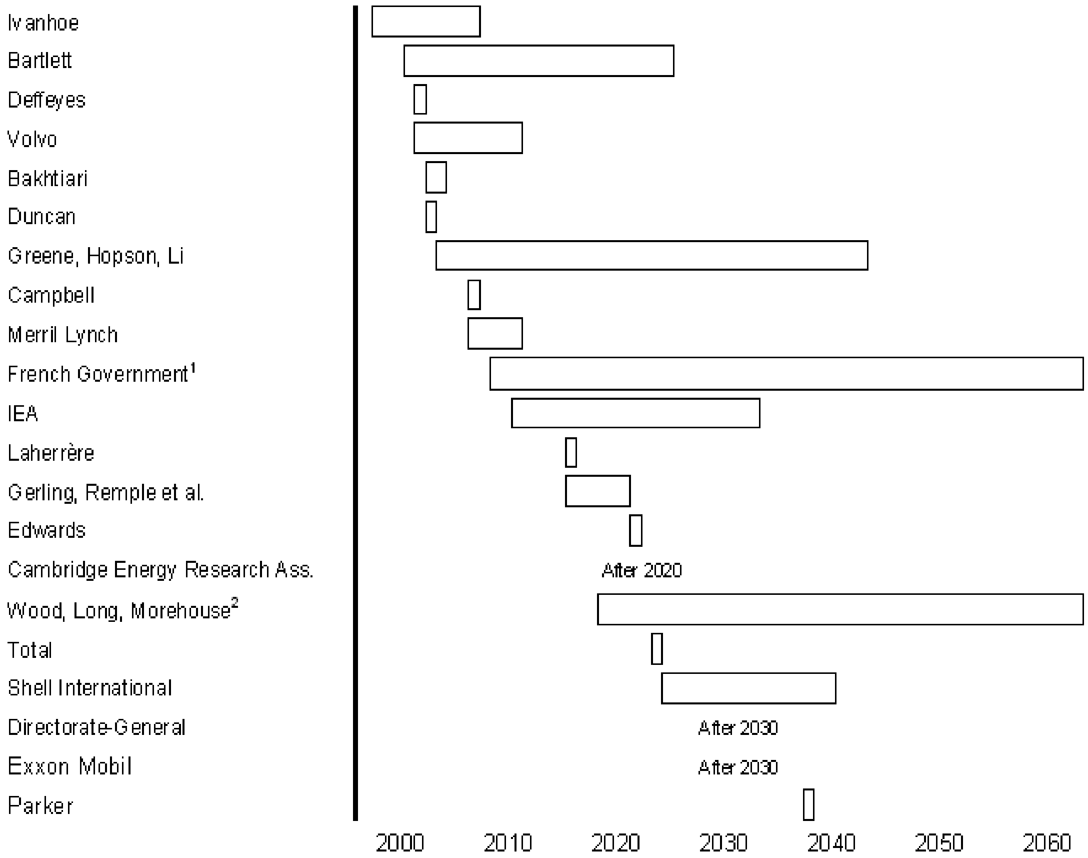
According to the International Air Transport Association (IATA) fuel outranked labor as largest single cost item in the global airline industry in 2006.[9] Fuel accounted for 25.5% of total operating costs in 2006 compared to 13.6% in 2001. The rise in fuel costs reflects a sharp increase in the price of crude oil but also a widening in the refinery margin.

Counteracting soaring fuel costs airlines intensified their efforts to improve fuel efficiency and to obtain cost savings in non-fuel cost items. In particular, labor productivity has improved resulting in a falling labor share of airline operating costs to 23.3% in 2006. The 25.5% fuel share of total operating costs calculated by IATA rests upon an average price of jet fuel of approx. $82 a barrel. With a kerosene price of $110 a barrel at the end of October 2007 the share of fuel costs further increases in the airline industry even if fuel hedging contracts lock a percentage of the fuel purchases at lower prices. Airlines react by increasing average prices for passenger tickets and rates for air cargo. For example, European airlines like Air France-KLM (AF-KLM) or Lufthansa raised their fuel surcharges for passenger tickets several times in 2007 (see Section 3).

Crude oil prices react to the balance of demand and supply. Hence, the current spiking of fuel prices creates concerns about a global shortage of future oil supplies. If actors in the oil market expect a shortage of oil supplies, oil prices increase before a shortage actually occurs. This is reflected in contracts for future deliveries of crude oil, called futures. In October 2007 the prices of crude oil futures soared to all-time highs after Energy Information Administration (EIA) said commercial US crude inventories dropped to the lowest level in two years. EIA providing the official energy statistics from the US government publishes an International Energy Outlook (IEO).[10] In the so-called reference case of its 2007 outlook, EIA projects a growth of world consumption of petroleum products by more than 40% from 84 mb/d in 2005 to 118 mb/d in 2030, an average annual growth rate of 1.4%. The demand of China grows much stronger with a forecasted rate of 3.5%. Strong growth is also projected for the other non-OECD economies with the exception of Russia. In addition to the reference case EIA also analyzes high and low oil price cases. Despite considerable differences between oil prices the demand projections for 2030 do not vary substantially indicating that long-term demand is relatively inelastic to oil price changes. The authors of this paper doubt that the suggested lack of demand elasticity remains a valid proposition once production of crude oil falls short of demand due to finite oil reserves.[11] Oil production would then also be a supply side constraint to the growth of worldwide kerosene consumption that leading airlines like Lufthansa still expect to increase about 40 percent until 2015.[12] If global crude oil production cannot be increased even with mounting oil prices there has to be a demand adjustment.

The US Government Accountability Office (GAO) - the audit, evaluation, and investigative arm of the US Congress - examined more than twenty studies on the timing of the peak in oil production conducted by government authorities, oil companies and oil experts (see Figure 3). According to this meta-analysis most studies estimate peak oil sometime between now and 2040. The range of estimates on the timing of peak oil is wide due to multiple and uncertain factors including (1) the amount of oil still in the ground, (2) technological, cost and environmental challenges to produce that oil, (3) political and investment conditions in countries where oil is located and (4) the future global demand for oil. Some of the studies cited by GAO consider only the peak in conventional oil, while other studies include non-conventional sources of oil – oil sands, heavy and extra-heavy oil deposits and oil shale. The production process of oil from non-conventional sources is more costly, uses larger amounts of energy and presents environmental challenges.

Figure 3: Estimates of the timing of peak oil (Source: GAO 2007)



1) End of estimated timespan is out of scale (2125)
2) End of estimated timespan is out of scale (2115)

According to the recently published energy outlook by the International Energy Agency (IEA) – the energy forum for 26 industrialized countries - the oil production in most countries outside the Middle East has already peaked or will do in the near future. Approximately 70% of the estimated remaining global oil reserves are located in politically insecure regions respectively are kept under OPEC control.[13] OPEC statements concerning strategic oil reserves may be questioned.[14] Oil production represents a major sector of economy in OPEC countries, and the admission of declining oil reserves harms their financial standing and political importance. In addition, the number of discovered oil fields decreases year by year.[15] About 42,000 oil fields have been discovered until today, the 400 largest represent about 75% of global oil reserves. The annual worldwide crude oil consumption exceeds the amount of discovered reserves since 1981. The predominant part of extracted crude oil nowadays derives from oil fields discovered in the 1970s.[16]

Finite oil resources and global economic growth lead to an upward trend for crude oil prices. However, due to multiple and uncertain factors concerning near-term and long-term oil production and the future development of global oil demand it is not surprising that forecasts on future prices show a wide range. In its international energy outlook 2007 EIA differentiates three world oil price cases.[17] In the high world oil price case, world oil prices climb from $43 per barrel (2005 real dollars) to $100 per barrel in 2030. In the low price case, oil prices moderate fairly quickly to $49 per barrel in 2010 and then further to $34 per barrel in 2015 and remain at that level through 2030. The reference case oil prices rise steadily after 2015 to $59 per barrel in 2030.

For the purpose of this exploratory paper we simply extrapolate the 50% increase of world oil prices in the one-year period Oct. 2006 – Oct. 2007 from a level of $60/barrel to $90/barrel for another year. This results in $135/barrel in Oct. 2008. This figure is not to be considered as another oil price forecast but only as starting point for the analysis of the possible short-term impact of higher kerosene prices on commercial aviation in Section 3. $135/barrel is beyond the oil price ranges of recently published short-term forecasts. In November 2007, EIA expects the average West Texas Intermediate (WTI) crude oil price in 2008 at nearly $80 per barrel.[18] However, most short-term oil price forecasts published in recent years underestimated the actual oil price development. For example, in January 2007 EIA also projected a WTI crude oil spot price of $65 for the 3rd and 4th quarter of 2007.

3 SHORT-TERM ECONOMIC IMPACT OF SOARING KEROSENE PRICES

This section considers the short-term response of passenger demand for air travel resulting from following cause-and-effect chain:

Crude oil price up ⇨ Kerosene price up ⇨ Fuel costs up ⇨
Air fares or fuel surcharges up ⇨ Air travel demand down

We refer to this cause-and-effect chain as *direct impact* of higher fuel prices. In addition, there are potential *indirect impacts* of soaring fuel prices, for example, a reduction in air travel demand resulting from lower disposable income of households or an increase in airlines' operating costs for other cost items than fuel due to inflation.

We assume no disruptions in normal economic activity and that the overall political and economic setting for commercial aviation remains intact. The time horizon is only one year from now allowing to differentiate a scenario with high level of airline fuel hedging and a scenario with no fuel hedging a year ahead. This short-term approach justifies not to account for fuel efficiency measures and also to use current operational and cost data. All calculations refer to European carriers and follow the methodology described in a series of papers by Grimme, Scheelhaase and co-authors.[19]

The volatility of kerosene prices is an important issue for the airline industry. In 2006, the fuel consumption of Lufthansa (LH) amounted to 6,940,587 tons[20] equivalent to 54,564,363 barrels (1 barrel = 159 liter, 1 liter kerosene = 0.8 kg). Hence, a fuel price rise by $1 a barrel increases LH's operating costs by more than $50 millions. Fuel hedging is often touted as the solution to this problem.

Fuel hedging means stabilizing fuel costs by locking in the costs of future fuel purchases to protect against sudden cost increases from rising fuel prices. Morrell and Swan (2006) point out that fuel hedging also prevents savings from decreasing fuel prices and might even lack a theoretical justification.[21] In practice, fuel hedging strategies vary significantly between airlines, some opting to hedge their entire fuel needs, while others leave themselves exposed to fluctuations in fuel costs. The lack of fuel hedging might not be strategy-driven but simply the result of insufficient cash or credit. According to Morrell and Swan, most airlines typically hedge between one- and two-thirds of fuel costs and look forward six months in their hedging, with few hedges more than a year ahead. Hence, the fuel hedging policy of AF-KLM with regard to the time period covered seems to be rather exceptional (see Table 1).[22]

Table 1: AF-KLM fuel hedging policy

	2007-08	2008-09	2009-10	2010-11
Forecasted spot price (Brent, $/barrel)	79	83	79	78
Hedged consumption (%)	77	67	51	31
Average hedged price (Brent, $/barrel)	62	61	68	69
Final average price (Brent, $/barrel)	66	68	73	75

Source: AF-KLM hedging policy for fuel expenditure (26th October 2007)[23]

AF-KLM forecasts a spot price of $79/barrel in 2007-08. The average fuel price for AF-KLM is locked with fuel-hedging contracts that secure 77% of the airline's fuel requirements in 2007-2008. Even for 2010-11 31% of the fuel needs are hedged. The average hedged price in 2007-08 with $62/barrel is only two thirds the spot price of crude oil at end of October 2007 of more than $90/barrel. By using the futures markets AF-KLM managed to soften the affect of higher fuel prices but still increased its fuel surcharges on air fares several times in 2007.

From the information publicly available, AF-KLM hedges only the crude oil price. This leaves the price difference between crude oil and kerosene uncovered. The kerosene price is driven by crude oil price developments but is also influenced by other specifics, especially refinery capacities and price switches between diverse oil products.[24] End of October, the spot price for kerosene-type jet fuel in Rotterdam was about $110 a barrel, i.e. approx. $20 higher than the spot price of Brent-Europe crude oil.

For the purpose of this exploratory paper we simply prolong the 50% increase of world oil prices in the one-year period Oct. 2006 – Oct. 2007 from a level of $60/barrel to $90/barrel for another year. This results in $135/barrel in Oct. 2008. As already stated in Section 2 this figure is not another oil price forecast but only serves as starting point for the analysis of the possible short-term impact of higher kerosene prices on commercial aviation. Additionally, we assume a constant refiner margin of $20. Hence, all further calculations are based on a spot price for kerosene-type jet fuel of $155 a barrel.

All airlines are confronted with volatility of fuel prices. Besides the structure of the fleet and network different fuel hedging policies lead to a varying effect on fuel costs among airlines. In Europe, network carriers like AF-KLM and LH pass along higher fuel costs to passengers through higher ticket prices with changing fuel surcharges added to air fares. Ryanair (FR) and other European LCCs do not add fuel surcharges but increase the average level of their fares. The purpose of the following calculations is to exemplify the likely increase in ticket prices and the resulting changes in passenger demand due to rising fuel prices. As reference value to measure fuel price increases we use the final average price of 68 \$/barrel forecasted by AF-KLM for 2008-09 by end of October 2007 (see Table 1). We refer to this fuel price as AF-KLM base. As no similar information about spot price forecasts, hedged and average fuel prices for LH and FR has been available to the authors, we simply assume that the AF-KLM base is also valid for FR and LH.

The airline's fuel costs (\$/liter kerosene) at a given future time (e.g. Oct. 2008) based on the future spot crude oil price, the airline's hedged consumption, the average hedged price and the refiner margin can be calculated as follows:

$$(1) \qquad C = ([\alpha \cdot p_h + (1-\alpha) \cdot p_s] + c_r)/159$$

with

C	Future fuel costs (\$/liter kerosene)
α	Share of fuel consumption hedged (%)
p_h	Average hedged crude oil price (\$/barrel)
p_s	Future spot crude oil price (\$/barrel)
c_r	Gross refiner margin (\$/barrel)

Assuming a spot price p_h= \$135 for crude oil in Oct. 2008, the AF-KLM fuel hedging policy (α=0.67; p_h=\$61) and a refiner margin c_r=\$20, the fuels costs (\$/liter kerosene) for AF-KLM in Oct. 2008 resulting from (1) amount to C= 0.66. In comparison, the AF-KLM forecast of a spot price p_h= \$83 for crude oil in Oct. 2008 (see Table 1) leads to C=0.56 other things being equal. Hence, even with a high level of fuel hedging fuel costs would be 18% higher than forecasted. In a scenario when fuel hedging contracts run out or no airline fuel hedging a year ahead (α =0) future fuel costs even rise to

C=0,97. To account for soaring fuel costs, airlines like AF-KLM increase fuel surcharges on passenger tickets.

The economic impact of higher fuel costs passed on to passengers via higher ticket prices is investigated for exemplary routes (see Table 2). Based on the operational data provided by Scheelhaase, Grimme and Schaefer (2007) following routes are analyzed:

- Frankfurt (FRA) – London-Heathrow (LHR) served by LH,
- Hahn (HHN) – London-Stansted (STN) served by FR and
- LH-operated intercontinental route FRA – Singapore (SIN).

For each route we differentiate the impact of fuel price increases with fuel hedging (α=0.67) and without fuel hedging (α=0). Results are compared with AF-KLM base of \$68/barrel. Lacking airline-specific information we assume that any increase in fuel costs in excess of the AF-KLM base (68\$/barrel) is fully passed on to passengers via higher ticket prices, i.e. fuel cost increase equals ticket price increase. FR has a no fuel surcharge policy and accommodates higher fuel prices by increasing average ticket prices. LH increases its fuel surcharge on air fares. In Oct. 2007 LH's fuel surcharge on long-haul tickets amounted to €67 per sector and for short-haul tickets €14 per sector.[25] This fuel surcharge has been increased several times by LH and other European carriers in 2007.

Table 2 shows fuel consumption and average passenger number per flight for the three selected exemplary routes. Based on this data, the route-specific future fuel costs per passenger in Dollar can be calculated for AF-KLM base as reference value (C=0.56) and two fuel hedging scenarios (C=0.66 and C=0.97) as follows:

$$c_{pax} = C \cdot \frac{k}{n} \tag{2}$$

with

c_{pax} Future fuel costs per passenger (\$/PAX)
C Future fuel costs (\$/liter kerosene)
k Fuel consumption per flight (liter kerosene)
n Avg. passenger number per flight (PAX)

As FR and LH denominate their ticket prices in Euro, fuel costs need to be converted into Euro as well. In Table 2 the Dollar/Euro exchange rate is €1 = \$1.45 (rate of end of October 2007).

Table 2: Increases in fuel costs and ticket prices due to higher kerosene prices

	Route	HHN-STN	FRA-LHR	FRA-SIN
	Carrier	FR	LH	LH
Operational data	Distance flown	572	695	10,603
	Aircraft type	B 737-800	A 321-100	A 340-300
	No. of seats	189	182	247
	Avg. seat load factor	76.1%	66.9%	80.5%
	Avg. no. of passengers	144	122	199
	Fuel consumption (liter kerosene)	3,250	4,125	107,500
Fuel costs (c_{pax})	AF-KLM base	12.6	18.9	302.6
	$\alpha = 0.67$	14.9	22.3	356.5
	$\alpha = 0$	21.9	32.8	524.0
Fuel costs (€/PAX)	AF-KLM base	8.7	13.0	208.7
	$\alpha = 0.67$	10.3	15.4	245.9
	$\alpha = 0$	15.1	22.6	361.4
	Avg. ticket price (per sector, €/PAX)	44	136	602
Abs. price increase (€/PAX)	$\alpha = 0.67$	1.6	2.4	37.2
	$\alpha = 0$	6.4	9.6	152.7
Rel. price increase	$\alpha = 0.67$	3.6%	1.8%	6.2%
	$\alpha = 0$	14.5%	7.1%	25.4%

The short-term impact of soaring kerosene prices on fuel costs and ticket prices depicted in Table 2 remains relatively moderate as long as fuel hedging by airlines mitigates fuel price increases. In absolute terms the price increase for the two short-haul routes is €1.6 (HHN-STN) and €2.4 (FRA-LHR) corresponding to a relative price increase per passenger and sector of 3.6% and 1.8% respectively. The higher price increase in per cent for Ryanair results from its significantly lower average ticket price per sector and passenger compared to Lufthansa which cannot be compensated by Ryanair's shorter flight distance and the higher average number of passengers per flight. For the long-haul route FRA-SIN the impact is already more pronounced, with an absolute price increase of €37.2 corresponding to 6.2% in relative terms. Note that even in a scenario with fuel hedging (α=0.67) the impact of increasing fuel prices is higher than the financial burden calculated by Scheelhaase et al. (2007) due to the introduction of the emission trading scheme as proposed by the European commission.

For the scenario when fuel hedging contracts run out or no airline fuel hedging (α=0) the impact is much stronger. In relative terms, Lufthansa's short-haul operation is less affected than the operation of Ryanair. The average ticket price sold by Lufthansa on FRA-LHR rises by 7.1% (€9.6) and Ryanair's price on HHN-STN by 14.5% (€6.4). The impact on surcharges on long-haul traffic largely exceeds the impact on short-haul traffic. For FRA-SIN operated by Lufthansa an additional fuel surcharge of €152.7 would occur. Based on an average fare per passenger and sector of €602.00, the additional fuel surcharge represents a relative fare increase of 25.4%.

€152.7 is the additional fuel surcharge calculated for Lufthansa resulting from assuming spot prices for crude oil to rise by 50% compared to current 90$/barrel and no softening of spot prices by fuel hedging. In principle, this paper equates short-term with a one-year horizon. In its hedging practice, LH hedges up to 90% of its planned fuel requirement on a revolving basis over a period of 24 months. In April 2007 even 70% is hedged one year ahead.[26] However, LH reduces its hedging ratio from this share each month by 5% leading to a growing exposure to fluctuations in fuel prices after one year. Hence, our results seem to overestimate the short-term impact of rising fuel costs on LH's fuel surcharge. However, FR has recently complained to EU over abusive increases in fuel surcharges based on spot prices on the global crude oil markets rather than hedged prices. According to FR, carriers like LH do not only increase ticket prices for passengers in lockstep with their higher fuel costs but even beyond their additional fuel costs.

As a result of shifting costs to passengers via higher ticket prices, demand for flights is expected to decrease. Table 3 shows how passenger demand reacts to higher ticket prices. The average price elasticities for short-haul leisure and business demand as well as for long-haul leisure and business demand are taken from a synoptic study by Gillen et al.(2004)[27], the shares of business travelers are adopted from Scheelhaase et al. (2007), and the relative increases in ticket prices from Table 2.

In the fuel hedging scenario (α=0.67), the estimated change in passenger demand for HHN-STN - a typical short-haul flight operated by FR - is -4.7%, while for LH's short-haul FRA-LHR and long-haul FRA-SIN it amounts to -2.0% and -4.0% respectively. Passenger demand for LCCs like FR will be much more negatively affected by soaring fuel prices than demand for full service network carriers like LH. The higher demand reduction for FR results from a higher relative fare increase compared to LH as well as a higher share of more price-sensitive leisure travelers. Compared to short-haul routes like FRA-LHR demand for long-haul routes such as FRA-SIN will be more affected due to the relative strong increase in ticket prices and despite lower price elasticities for long-haul travel.

Without fuel hedging (α=0), the short-term impact on passenger demand is even stronger. The estimated change in passenger demand due to higher ticket prices for HHN-STN is -19,1%, -7.9% for FRA-LHR and -16,6 % for FRA-SIN.

Table 3: Demand reduction due to higher ticket prices

Route	HHN-STN	FRA-LHR	FRA-SIN
Carrier	FR	LH	LH
Avg. price elasticity, business	-0.7	-0.7	-0.265
Avg. price elasticity, leisure	-1.52	-1.52	-1.04
Share of business travelers	25%	50%	50%
Relative price increase for α = 0.67	3.6%	1.8%	6.2%
Relative price increase for α = 0	14.5%	7.1%	25.4%
Change in demand for α = 0.67	-4.7%	-2.0%	-4.0%
Change in demand for α = 0	-19,1%	-7,9%	-16,6%

We have simplified our exploratory analysis by not differentiating the relative price increases with regard to leisure and business market segments. As the average ticket price per passenger is higher for business travelers compared to leisure travelers, the reduction in leisure demand is even stronger and the reduction in business demand lower than shown in Table 3.

In this section we only estimated the isolated effect of soaring fuel prices transmitted via higher ticket prices on passenger demand. We previously defined this cause-and-effect chain as direct impact of higher fuel prices. There will be indirect impacts of soaring fuel prices, for example, a reduction in air travel demand resulting from lower disposable incomes. Looking at the calculated short-term reduction in passenger demand of more than 15% for typical short-haul services operated by LCC as well as for long-haul services in the no fuel hedging scenario, higher ticket prices due to soaring fuel prices strongly influence commercial aviation. However, this direct impact may be compensated by other factors influencing travel demand. Scheelhaase et al. (2007) point out that fuel surcharges levied by airlines in recent years did not keep aviation from growing more than 5% annually. In addition, the estimated changes in passenger demand for services offered by FR and LH have to be set in due proportion to the future growth trend in commercial aviation, especially the currently expected growth rates for European LCCs that go well beyond 5% p.a.[28] The reduction in air travel demand caused by soaring fuel prices may only confine the overall demand increase.

4 ALTERNATIVES TO KEROSENE AS JET FUEL

The previous results show that the rate of air traffic growth constrained by scarcity of kerosene will be much lower - and may even be negative - than unconstrained air traffic growth, especially leading to a strong reduction of demand for leisure traffic and long-haul services. Hence, the entire aviation industry has to look beyond the fuel-efficient '3 liter aircraft' and search for new groundbreaking ways to become less dependent on fossil fuels. This section provides a brief overview how to save fuel or even replace kerosene as jet fuel.

At present, aircraft and engine manufacturers improve aircraft design (e.g. blend wing aircraft) and fuel-efficiency of engines in order to reduce fuel consumption. Fuel saving strategies by airlines include

- shorter air routes,
- carrying less minimum fuel,
- shorter sector lengths,
- modern fleet
- increased load factors
- more efficient ground operations (e.g. reduction of ground delays).

All these efforts contribute to a reduction in fuel consumption by commercial aviation but do not provide a substitute to conventional petroleum kerosene.

Kerosene is considered the ideal jet fuel.[29] First reason is its high energy content. The energy content of fuel is measured as specific energy which is the energy content per unit mass (joules/kg) and as energy density which is the energy per volume (joules/liter). The high energy content of kerosene positively affects the total size and weight of the aircraft. Operationally, the heavier the aircraft is at takeoff, the more fuel is required to lift it into the air.

With regard to safety criteria, the Jet A-1 kerosene used in commercial aviation has a high flash point and a low freezing point Kerosene also does not contain or absorb water which means that in cold temperatures no ice crystals form that block fuel filters and ultimately lead to fuel starvation. These safety over a wide temperature range is very important selection criteria for alternative fuels.

In the following, an overview of three currently discussed alternative fuels - synthetic kerosene, hydrogen and biofuels - is given. Fuel cells as a new aircraft propulsion technology are also briefly discussed. Alternatives to conventional kerosene have to meet following criteria:

- high energy content,
- safety criteria,
- environmentally clean,
- global availability and costs
- short-term availability .

Synthetic kerosene

Synthetic kerosene can be made from coal, natural gas or biomass. Based on the raw materials used the three methods of production are differentiated:

- biomass to liquid (BTL),
- gas to liquid (GTL) and
- coal to liquid (CTL).

Synthetic kerosene is currently only approved in commercial aviation as a blend with petroleum kerosene. In direct comparison to BTL and GTL, the production of CTL generates more CO_2. Natural gas and coal have the disadvantage of all finite resources that they will ultimately run out . BTL can be produced from almost any type of biomass and offers new perspectives for farmers but also implies the risk of competition with agricultural use. BTL contains no sulfur and the combustion process releases CO_2

in the same quantity as the plants have absorbed from the atmosphere prior to their growth process.[30]

Hydrogen

Hydrogen is probably the most commonly discussed alternative to kerosene. It provides 2.5 times the energy per kg than kerosene, .but the volume would be 2.5 times that of an equivalent amount of kerosene. Today, hydrogene is expensive to produce and difficult to store requiring a lot of electrical power and a large source of clean water.[31]

A major potential advantage of hydrogen compared to kerosene is the significant reduction of harmful emissions. Hydrogen emits no carbon dioxide (CO_2), no carbon monoxide (CO), no unburned hydrocarbons (HC) and no sulfuric acid (SO_2).The only common secondary emissions of importance are nitrogen oxides (NO_x). The only primary combustion product of hydrogen is water (H_2O) leading to more water vapour than kerosene.

Due to the large volume and the requirement to cool down hydrogen to the liquid state (-253° C), the cryogenic storage of hydrogen constitutes a major challenge for aircraft manufacturers A hydrogen powered aircraft will look very different from today's aircraft design. Hydrogen cannot be stored in the wings because of pressurization and insulation requirements. Hence, the fuel tanks have to be implemented in the fuselage. This may result in an enlarged fuselage or less passenger capacity. Furthermore, the engines hydrogen-fueled aircraft have to be redesigned.

Hydrogen-powered aircrafts also pose a major challenge for airport infrastructure which today is only designed for kerosene-powered aircrafts. A prerequisite for a change to hydrogen-powered aircrafts and already in the transition stage from kerosene are two parallel fueling systems at airports worldwide. Hence, a transition to a hydrogen-driven aviation may take decades, especially considering the long life-span of aircrafts currently in operation.

Biofuels

Biofuels refer to the use of biodiesel and alcohol like ethanol and methanol. Ethanol and methanol are not suitable to replace kerosene because of chemical and physical properties such as being very corrosive. Biodiesel is also not considered as an alternative on its own due to its high flash point, low volatility, need for high pressure, and because it thickens and crystallizes at the temperature found at jet cruising levels.[32] Biodiesel is a more By blending with other fuels or the use of additives the low temperature operability of biodiesel could potentially be improved.[33] Biodiesel is currently approved as a kerosene extender at concentrations up to 10%.

Fuel cells

Fuel cells have been used in spacecrafts since the 1960's to power auxiliary engines. The development of an "all electric aircraft" with electric engines driven by fuel cells is on its way. The main challenge is to develop compact, lightweight electric propulsion systems with more power. Today, electric motors weigh up to five times as much as regular jet engines and is far from their efficiency.[34]

A superconducting motor may result in a higher energy content but brings up a new problem. The superconducting magnets have to be cooled. The cooling could be assured by liquid hydrogen. These fuel cells would not emit carbon dioxide, just warm water. Another benefit is the noise reduction because of the use of electric motors.

Table 4 summarizes the pros and cons of the alternatives to petroleum kerosene along selected criteria. The assessment does not account for ground-breaking technology developments and, hence, has to be regarded as preliminary. Considering alternatives to petroleum kerosene in the immediate future, synthetic fuels holds the greatest promise as it can in principal be used in existing aircraft either alone or blended with petroleum kerosene. The main problem for synthetic fuels is the large amount of CO_2 generated during production. In the long-run , hydrogen seem to be the most promising candidate to replace kerosene but asks for ther introduction of a completely new aircraft design and new ground infrastructure.

Table 4: Assessment of alternatives to kerosene as jet fuel

		High energy content	Safety criteria	Environmentally clean	Global availability and costs	Short-term availability
Synthetic kerosene	**BTL**	o	+	+	o	+
	CTL	o	+	-	o	+
	GTL	o	+	-	o	+
Hydrogen		+	?	+	-	-
Biofuels		-	-	o	+	+
Fuel cells		-	+	+	o	-

5 CONCLUSIONS

Conventional wisdom in commercial aviation is that global air traffic will continue to grow in the coming decades. This implicitly assumes no constraint in traffic growth due to finite oil resources. This is in stark contrast to studies that estimate peak oil sometime between now and 2040.

This exploratory paper analyzed the short-term economic impact of soaring fuel prices on commercial aviation. The time horizon was only one year from now allowing fuel hedging by airlines to balance increasing spot prices. The analysis was restricted to the direct effect of higher kerosene prices on operating costs, fare levels and passenger demand. Indirect effects on passenger demand resulting from a reduction of purchasing power, an increase in unemployment and higher costs for other input factors besides kerosene were not considered. Our scenarios also ignored possible political crisis and economic shocks for oil importing countries forced to spend significantly more on their energy purchases. Hence, the scope of this paper has been somehow limited.

However, our limited approach already shows that the rate of air traffic growth constrained by scarcity of kerosene will be much lower - and may even be negative - than unconstrained air traffic growth, especially with regard to price-sensitive leisure demand. Our results indicate that services offered by low-cost carriers and long-haul services will be most adversely affected by higher fuel prices. Further, comparing the impact of soaring fuel prices with the one resulting from the heavily discussed introduction of the EU emission trading system (ETS) for the European aviation industry we conclude that the relative effect of ETS is much lower. This leads to the question whether ETS is actually needed in view of finite supplies of fossil fuels that may restrict or even terminate air traffic growth. In addition, high fuel prices will be a strong incentive to use more fuel-efficient engines, to optimize minimum fuel policies, to improve air routes and ground operations, etc., in the same direction as intended by ETS.

The fuel price development will also influence the typical air service pattern, for example, there may be a renaissance of technical stops for re-fueling on intercontinental routes or more point-to-point traffic in order to avoid fuel burning detours via hubs. To avoid high fuel costs, regional carriers have already replaced regional jets on some routes by turboprops. The in-depth analysis of the relative economic benefit of competing services patterns and the use of turboprops instead of regional jets in times of high fuel prices is an interesting issue for further research.

Peak oil will happen, the only uncertainty is when. It is a problem that may soon eclipse the global warming debate in commercial aviation.[35] Aviation industry and politicians better face the long-term implications of finite oil resources. Airline and airport managers should no longer exculpate themselves by referring to future air frame designs to be developed by aircraft manufacturers or increased blending of other fuels with kerosene by the petrochemical industry. More research than today should be devoted to the economic evaluation of kerosene substitutes in combination with the associated future requirements for airline fleets and airport infrastructure.

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