JOHANNES KEPLER UNIVERSITY LINZ

DEPARTMENT OF ECONOMICS
JOHANNES KEPLER UNIVERSITY OF LINZ

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by

Jochen GÜNTNER

Peter ÖHLINGER

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Johannes Kepler University of Linz
Department of Economics
Altenberger Strasse 69
A-4040 Linz - Auhof, Austria
www.econ.jku.at

Corresponding author: jochen.guentner@jku.at

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Jochen Güntner†

JKU Linz

Peter Öhlinger

JKU Linz

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Abstract

In the light of finite oil reserves, Persian Gulf oil-exporting economies have recently undertaken major investments in their domestic travel and tourism industries. Building on the Bayesian SVAR model of the global oil market in Baumeister and Hamilton (2019), we investigate the conditional comovement of airline stock returns with real oil prices in response to structural oil supply and demand shocks. We find that investing in the Datastream World Airline Index offers a hedging benefit conditional on oil supply, consumption demand, and inventory demand shocks, whereas there is no evidence of systematic positive or negative comovement following shocks to world economic activity and airline stock returns.

Keywords: Airline excess returns; Bayesian SVAR model; Hedging; Oil price shocks

JEL classification: C32; L71; L93; Q41

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†Corresponding author: Jochen Güntner, Johannes Kepler University (JKU) Linz. Altenberger Straße 69, 4040 Linz, Austria. Telephone: (+43)(0)732 2468 7360. Email: jochen.guentner@jku.at.

1 Introduction

In the face of exhaustible crude oil reserves, Persian Gulf oil exporting economies have recently undertaken substantial investments in the aviation and tourism industry. Serving as a hub between Europe, Africa, and Asia, Doha, for example, enjoys a comparative advantage over hubs in the U.S. or Western Europe. Given the historical volatility of world oil prices, oil-exporting economies are exposed to substantial financial risks. Investments in an energy-intensive industry, the returns of which correlate negatively with world oil prices, may buffer short-term fluctuations in national revenue due to shocks in the global oil market.

In 2020, 48.04% of the world's proven crude oil reserves were located in only seven Persian Gulf countries.[1] The regional map in Figure 1 contains information on 2016 crude oil exports, proven crude oil reserves, and the approximated daily loss in oil revenues due to the oil price plunge of 2015.[2] In light of the exhaustibility of petroleum reserves and the recent volatility of world oil prices, oil revenues come along with major short-term and long-term challenges (see, e.g., Collier et al., 2010). The loss of oil revenues during 2014–2015 highlights the risk of unexpected drops in national income and budgetary deficits faced by countries that are heavily dependent on oil exports. Even though Saudi Arabia slightly increased the *volume* of its oil exports in 2015, the plunge in oil prices lowered the average daily *value* of its oil exports by $311 million. Figure 1 also depicts the location of international aviation hubs in the region and the percentage change in fleet size for six major state-owned airlines during 2008–2018.[3] While Kuwait Airways and Saudi Arabian Airlines have grown at a similar pace as international competitors, such as Lufthansa (+42.9%), Southwest Airlines (+39.7%), and Air France-KLM (−11.6%), the fleet size of Emirates, Etihad Airways, Oman

[1] Namely Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates. Four of these countries are among the founding members of the Organization of the Petroleum Exporting Countries (OPEC), while five of them are among the worlds top-seven crude oil exporters in 2016.

[2] The approximated loss in oil revenues is calculated as the change in the value of oil exports from 2014 to 2015, when the annual average of the U.S. Energy Information Administration's (EIA) refiner acquisition cost of imported crude oil dropped from $89.6 to $46.5 per barrel — the largest historical drop in the annual average oil price recorded by the EIA.

[3] No reliable data on fleet size are available for Iran Air and Iraqi Airways.

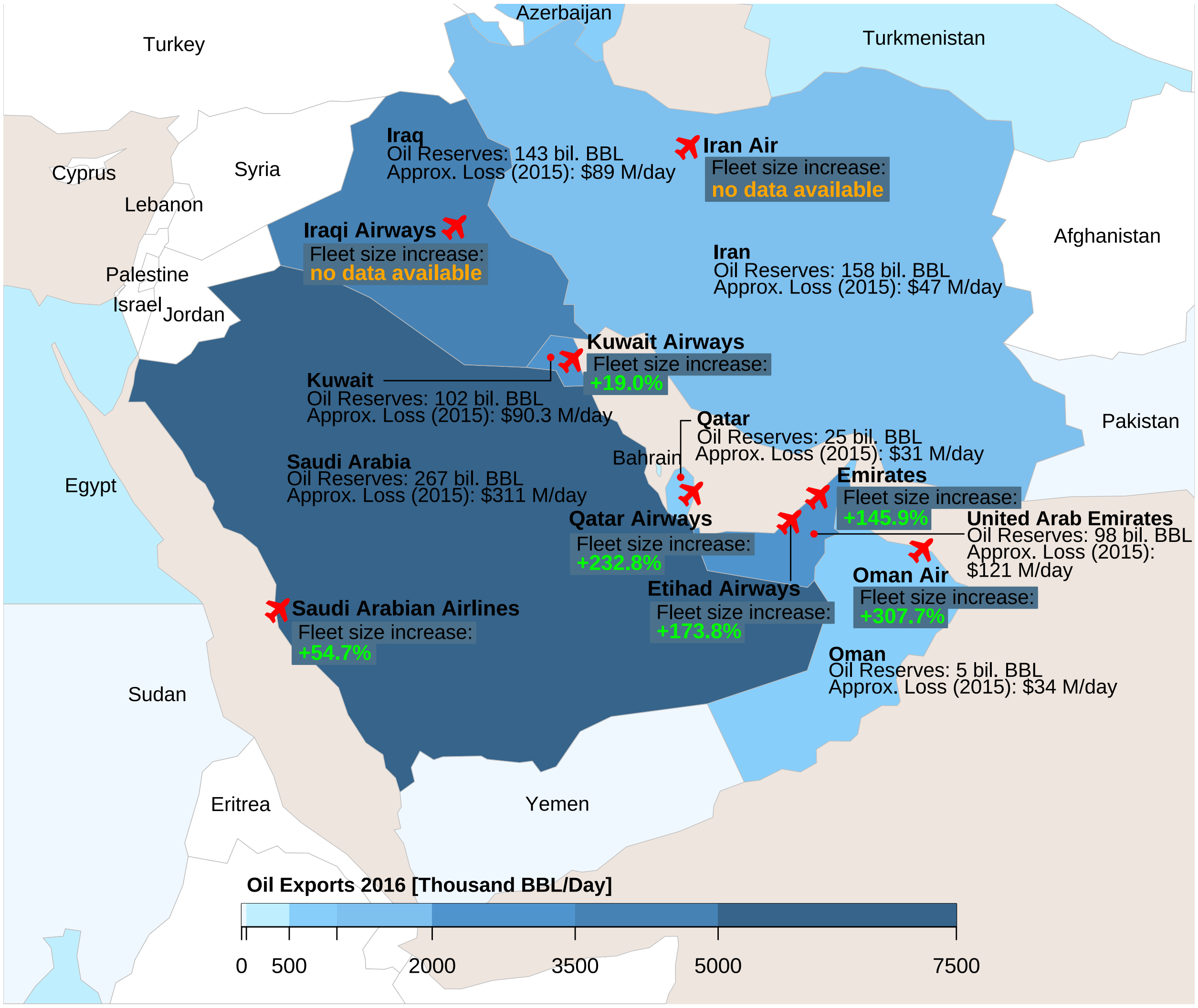


Figure 1: Oil export volumes and fleet size growth of state-owned Persian Gulf airlines

Notes: Heatmap of 2016 oil exports in thousand barrels per day (tbpd), proven crude oil reserves (as of 2016), and approximated loss of oil revenues due to the oil price drop of 2015 for seven Persian Gulf countries. Airplane symbols indicate the location of hubs for eight state-owned airlines with the respective percentage change in fleet size during 2008–2018.

Sources: EIA, Annual reports of airlines, International Civil Aviation Organization, Hooper et al. (2011)

Air, and Qatar Airways has increased by 145.9%, 173.8%, 307.7%, and 232.8%, respectively, even outpacing Alaska Airlines (+95.3%) and Ryanair (+169.9%). Besides their geographic location, airline investments of oil exporters in the Persian Gulf may also be motivated by hedging considerations, if jet fuel costs are a nontrivial share of total operating expenses.

In this paper, we extend the Bayesian structural vector-autoregressive (SVAR) model of the global oil market in Baumeister and Hamilton (2019) by an additional equation for airline excess returns, specifying uninformative prior distributions for the additional parameters in the model. Given the lack of publicly available balance sheet and stock price data for any of the state-owned Persian Gulf carriers, we use the Datastream (DS) World Airline Index (WAI) as a proxy for current and future expected profits in the global airline industry during 1974:2–2019:12 to investigate whether airline investments qualify as a hedging instrument for heavily oil-dependent economies. Distinguishing between structural oil supply and demand shocks reveals that this is not always the case.

We find that real oil price growth and WAI excess returns over the DS World Market Index comove negatively in response to a typical oil supply, oil consumption demand, and oil inventory demand shock, respectively, while there is little evidence of systematic (positive or negative) comovement in response to a typical shock to world economic activity or airline excess returns. Using historical decompositions, we also find that the former three structural shocks induced negative comovement between real oil price growth and WAI excess returns during selected episodes such as the OPEC collapse in 1986 or the Gulf War in 1990–1991. Finally, we show that real oil price growth and WAI excess returns are negatively correlated conditional on the historical composition of structural oil supply and demand shocks. We therefore conclude that financial investments in the WAI come along with a hedging benefit against exogenous fluctuations in real oil prices. Extending our analysis to individual airlines and related industries reveals some heterogeneity in hedging potential between low-cost and legacy carriers as well as between the DS World Hotel and World Travel & Tourism Index.

1.1 Preliminary Evidence

A necessary condition for a hedging benefit of airline investments is that profits in the industry are more sensitive to oil price fluctuations than in other industries. The following statement from German Lufthansa Group's 2018 annual report provides anecdotal evidence for this condition:

> *"Severe fluctuations in fuel prices can have a significant effect on the operating*

Table 1: Jet fuel costs of major U.S. and European airlines (2004–2020)

Year	**Alaska Airlines**		**Southwest Airlines**		**Lufthansa**		**Air France-KLM**	
	Jet fuel costs (millions)	Percentage of operating expenses	Jet fuel costs (millions)	Percentage of operating expenses	Jet fuel costs (millions)	Percentage of operating expenses	Jet fuel costs (millions)	Percentage of operating expenses
2004	$ 136	23.1%	$ 1,106	18.1%	€ 1,819	9.6%	€ 1,990	12.7%
2005	$ 549	19.5%	$ 2,580	21.4%	€ 2,662	14.0%	€ 2,653	12.9%
2006	$ 873	25.3%	$ 2,284	28.0%	€ 3,355	16.5%	€ 3,588	16.4%
2007	$ 876	26.6%	$ 2,690	29.7%	€ 3,860	17.1%	€ 4,258	18.8%
2008	$ 944	24.6%	$ 3,713	35.1%	€ 5,377	21.0%	€ 4,572	19.0%
2009	$ 988	31.5%	$ 3,193	31.2%	€ 3,645	14.7%	€ 5,703	25.6%
2010	$ 900	26.8%	$ 3,755	33.4%	€ 5,158	17.9%	€ 4,720	20.1%
2011	$ 1,298	33.5%	$ 5,751	38.2%	€ 6,276	20.6%	€ 5,720	23.1%
2012	$ 1,459	35.4%	$ 6,156	37.3%	€ 7,392	23.3%	€ 7,328	26.6%
2013	$ 1,467	34.0%	$ 5,823	35.3%	€ 7,115	22.7%	€ 6,897	27.2%
2014	$ 1,418	32.2%	$ 5,355	32.6%	€ 6,751	21.5%	€ 6,629	26.5%
2015	$ 954	22.2%	$ 3,740	23.6%	€ 5,784	17.3%	€ 6,183	24.8%
2016	$ 831	18.1%	$ 3,801	22.7%	€ 4,885	15.4%	€ 4,597	19.3%
2017	$ 1,447	21.6%	$ 4,076	23.0%	€ 5,232	14.8%	€ 4,507	18.8%
2018	$ 1,936	25.4%	$ 4,616	24.6%	€ 6,087	17.2%	€ 4,958	19.7%
2019	$ 1,878	24.3%	$ 4,347	22.3%	€ 6,715	18.1%	€ 5,511	21.1%
2020	$ 723	13.5%	$ 1,849	14.4%	€ 1,875	9.0%	€ 2,392	15.3%

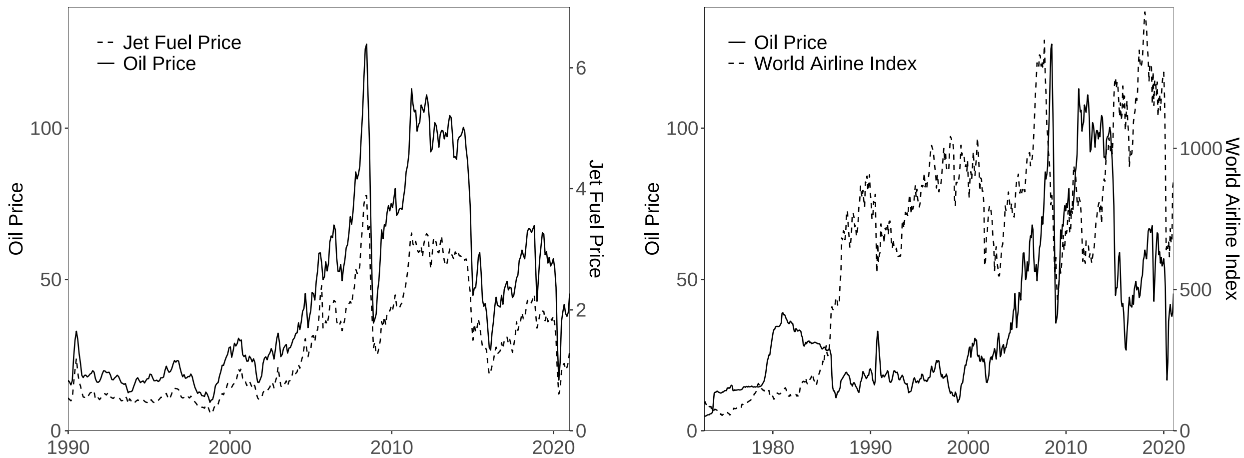
Source: Annual reports of airlines

> *result. A change in the fuel price of +10% (-10%) at year-end 2019 would increase (reduce) fuel costs for the Lufthansa Group by EUR 343m (EUR −319m)* ***after hedging****.”*

Similar statements in the annual reports of publicly listed companies highlight the sensitivity of industry profits to unexpected oil price hikes *even after engaging in hedging activities*.[4]

Table 1 reports annual jet fuel costs of Alaska Airlines, Southwest Airlines, Lufthansa, and Air France-KLM in nominal terms and in percent of operating expenses for 2004–2020. While the table highlights the general importance of fuel costs in airline operating expenses, it also reveals substantial heterogeneity across carriers and over time. In 2012, jet fuel costs as a fraction of operating expenses amounted to 23.3 and 26.6% for Lufthansa and Air France-

[4]Due to the lack of transparency of state-owned Persian Gulf airlines, for which financial statements are generally not available, our empirical analysis rests on excess stock return data for the WAI and major U.S. and European airlines, such as Lufthansa.



(a) Refiner acquisition cost of imported crude oil (in $ per barrel) and kerosene-type jet fuel price (in $ per gallon, U.S. Gulf Coast)

(b) Refiner acquisition cost of imported crude oil (in $ per barrel) and Datastream World Airline Index

Figure 2: Historical evolution of crude oil prices, jet fuel prices, and airline stock prices

KLM, respectively, yet more than 35% for Alaska Airlines and Southwest Airlines, indicating different cost structures in particular of European legacy and U.S. low cost carriers. In 2004, at an annual average oil price of $35.8 per barrel (according to the U.S. refiner acquisition cost of imported crude oil), U.S. and European airlines reported jet fuel costs of around 20% and 10% of operating expenses, respectively. Eight years later, at an annual average oil price of $101.1 per barrel, this share had increased by 50% for Alaska Airlines and more than doubled for Southwest Airlines, Lufthansa, and Air France-KLM.

Figure 2a illustrates the historical comovement between the price of crude oil and the price of kerosene during 1990–2018. At the monthly frequency, the unconditional correlation amounts to .992. Accepting that jet fuel is a substantial cost factor in airline operating expenses and that its price comoves closely with that of crude oil, airline investments represent a potential candidate for hedging against exogenous fluctuations in oil revenues.

A sufficient condition for hedging is that airline revenues increase when oil prices decrease and vice versa. Figure 2b plots the U.S. refiner acquisition cost of imported crude oil against the WAI for 1973–2018. Until the early 2000s, lower oil prices are indeed associated with higher values of the WAI. However, this association seems to break down during the global economic boom preceding the financial crisis, when oil prices and airline stock prices tend to comove positively before reverting to the previously observed pattern around 2010. Checking whether the second condition holds therefore requires a structural model of crude oil prices and airline stock returns.

1.2 Related Literature

At the corporate level, hedging is a common practice used primarily to manage fluctuations in commodity prices (see, e.g., Bodnar and Gebhardt, 1999). Oil-intensive industries, such as transportation, are directly affected by oil price fluctuations and engaging in hedging activities may thus be beneficial. Carter et al. (2006), for example, show that U.S. airlines hedging against unexpected *hikes* of jet fuel prices benefit twofold. Their stocks trade at a premium, and they are able to acquire assets from distressed airlines during times of high oil prices. This evidence is corroborated by Campello et al. (2011), who show that hedging raises a firm's ability to access capital and invest. While it is not surprising that oil-intensive industries may benefit from hedging activities, Nandha and Faff (2008) argue that exogenous oil price hikes induce negative effects on stock returns also in relatively less oil-dependent industries due to indirect channels such as consumer confidence, interest rates or the price of intermediate inputs, for example.

In light of the immediate effect on profits, oil producers may conversely be interested in hedging against unexpected oil price *drops*. Studying U.S. oil and gas producers, however, Jin and Jorion (2006) find no evidence that hedging raises a firm's market value and argue that oil price risks are effectively hedged by individual investors. While hedging does not seem to affect oil and gas producers' market *values*, it is negatively correlated with their market *betas*, implying that hedging reduces the firm's stock price sensitivity to energy prices. Accordingly, Daniel (2002) suggests that small oil-exporting countries without noticeable influence on world oil markets may engage in such hedging strategies, whereas major oil exporters are likely unable to offset their oil price risk completely. Bjørnland and Thorsrud

(2019) furthermore show that, even in a resource-rich developed country, such as Norway, fiscal policy rules fail to insulate the domestic economy from oil price shocks.[5]

This raises the question how oil-exporting countries in the Persian Gulf may hedge their oil price risk and stabilize national revenues. Studying the response of global equity markets to oil price hikes, Nandha and Faff (2008) find a negative relationship for all sectors except mining, oil and gas. Adapting this result to oil-exporting countries, hedging potential may arise from the advancement of industries that benefit from low oil prices. Considering past and future planned investment projects in the Persian Gulf, there is ample anecdotal evidence of a focus on transport and tourism. Besides the establishment of airports as international hubs, state-owned Persian Gulf airlines have experienced an unprecedented growth in fleet size, route network, and number of passengers (see Figure 1). Vespermann et al. (2008), for example, interpret this expansion of the airline industry as part of a diversifying strategy. If the returns on airline investments are negatively correlated with world crude oil prices, they may furthermore compensate at least partially for shortfalls of oil export revenues due to exogenous oil price fluctuations.

Even though unconditional correlations, such as in Figure 2b, do not allow for a definite conclusion, Faff and Brailsford (1999), Elyasiani et al. (2011), Scholtens and Yurtsever (2012), and Yun and Yoon (2019) report a *negative* association between oil prices and transport sector stock returns for Australia, the U.S., Europe, and Asia, respectively. Applying the Fama and French (2015) five-factor asset pricing model augmented by an oil price risk factor, Shaeri et al. (2016) identify airlines as the U.S. sub-sector with the largest negative exposure to oil price risk during 1983–2015. Using a four-factor asset pricing model, Mohanty et al. (2014) report a significant negative impact of oil price shocks on airline industry returns.

However, none of these studies explains the positive comovement of oil prices with the WAI prior to the Financial Crisis of 2007–2008. Using different GARCH models derived from the Capital Asset Pricing Model (CAPM) to study daily stock prices of 56 International

[5]Conversely, Aastveit et al. (2015) quantify the relative importance of crude oil demand from emerging and developed economies as exogenous drivers of the real price of oil.

Air Transport Association (IATA) airlines, Kristjanpoller and Concha (2016) instead find a strong *positive* association between jet fuel prices and airline stock returns. Interpreting oil price hikes as a signal of strong current or expected future economic growth, the authors attribute this finding to market inertia.

In the spirit of Kilian (2009), Kilian and Murphy (2012, 2014), Baumeister and Peersman (2013), and Zhou (2020), we reconcile the seemingly contradictory results in the literature by distinguishing between structural oil supply and demand shocks. For this purpose, we follow Baumeister and Hamilton (2018) and Aastveit et al. (2021) and extend the Bayesian SVAR approach in Baumeister and Hamilton (2019) by augmenting their baseline four-equation model of the global oil market with a fifth equation for airline stock returns.[6] This allows us to investigate the comovement of crude oil prices with airline stock returns conditional on a typical oil supply or demand shock, during selected historical episodes as well as conditional on the historical composition of structural oil price shocks.

The remainder of this article is structured as follows: Section 2 introduces the oil market and stock market data. In Section 3, we describe the econometric methodology, our adjustments to Baumeister and Hamilton (2019), and the specification of Bayesian priors for the parameters of the structural model. Section 4 presents and discusses our empirical results, while Section 5 concludes.

2 Data

We are interested in the comovement of crude oil prices and airline stock returns after a structural oil supply or demand shock. For this purpose, we augment the 4-variable SVAR model in Baumeister and Hamilton (2019) with a fifth endogenous variable. In this section, we discuss the data underlying the oil market block and the measures used in the additional stock market equation.

[6] Accordingly, the econometric approach is similar to Kilian and Park (2009) and Güntner (2014), albeit based on a different (i.e. non-recursive) oil-market block.

2.1 Oil market data

Following Kilian (2009) and Kilian and Murphy (2012, 2014), we use the month-on-month growth rate of world crude oil production available from the U.S. Energy Information Administration (EIA) as a measure of the quantity of oil supplied in the global oil market.

As a measure of global real economic activity, we use the extended version of the OECD's industrial production index proposed by Baumeister and Hamilton (2019), which comprises monthly industrial production in the OECD as well as six major non-OECD economies.[7]

As a measure of world crude oil prices, we use the EIA's U.S. refiner acquisition cost of imported crude oil (in $ per barrel), which we deflate by the U.S. consumer price index for all urban consumers and items. Following Baumeister and Hamilton (2019), both the world industrial production index and the real price of crude oil enter the structural VAR model in month-on-month growth rates (i.e. in log differences times 100).

Kilian and Murphy (2014) emphasize the importance of oil inventories above the ground for interpreting the short-run dynamics of prices and quantities in the global oil market, since an increase in oil production in any given period may either be consumed or raise inventories and thus the amount of crude oil available in future periods. Given that a measure of world crude oil inventories is not readily available even today, Kilian and Murphy (2014) construct an estimate based on OECD petroleum product inventories from 1988 onwards and back-cast changes in OECD product inventories using the growth rate of U.S. petroleum product inventories prior to 1988. Baumeister and Hamilton (2019) point out that the resulting time series likely contains measurement error and that OECD petroleum product consumption accounts for about 60% of world petroleum product consumption on average during 1992–2015. Hence, we follow the approach in Baumeister and Hamilton (2019) and presume that the proxy for crude oil inventories proposed by Kilian and Murphy (2014) is only part of the

[7] Alternatively, we could have used the index of global real economic activity based on single-voyage dry-cargo ocean shipping freight rates constructed in Kilian (2009), which measures the demand for industrial commodities other than crude oil and was corrected in Kilian (2019) in response to Hamilton (2019)'s critique. For consistency with the identifying assumptions of Baumeister and Hamilton (2019), we stick to the proxy for world industrial production in our baseline specification.

world total and measured with error. In contrast to the other variables, inventories enter the structural VAR model in terms of month-on-month changes as a percentage of world crude oil production.[8]

2.2 Stock market data

All stock price and stock index data are obtained from Refinitiv Datastream (DS). Besides quotes for individual stocks, DS provides industry-specific and regional market indices. Each DS market index is based on a representative sample covering at least 75–80% of the market's total capitalization. Individual stocks are assigned to industrial sectors using the Industry Classification Benchmark (ICB). Figure A.1 in the appendix illustrates the DS classification system and shades the layers and industries of primary interest in this study.

In our baseline analysis, we investigate the conditional comovement between real oil prices and the DS World Airline Index (WAI) as a proxy for discounted future profits in the global aviation industry.[9] When zooming in on individual stocks, we are confined to four publicly listed international carriers. Hence, we investigate the conditional comovement between real oil prices and the stock prices of Alaska Airlines (U.S.), Lufthansa (Germany), Air France-KLM (France, Netherlands), and Southwest Airlines (U.S.). While the latter are not necessarily representative for the respective national airline industries, they satisfy the prerequisite of a sufficiently long and consistent history of stock prices.[10]

The rapid expansion of airlines and hubs in the Persian Gulf is accompanied by an equally rapid expansion of the hotel and travel and tourism (T&T) sector. Given that profits in these sectors tend to correlate with or hinge on the airline industry, we also investigate the conditional comovements between real oil prices and the DS World Hotel and T&T indices

[8] We focus on the second subsample in Baumeister and Hamilton (2019), given that consistent monthly data on all oil market variables — especially the U.S. refiner acquisition cost of crude oil — is only available from January 1974 (see also Kilian and Vigfusson, 2011).

[9] For the current composition of the WAI, see Table A.1 in the appendix.

[10] In 2019, Southwest Airlines and Alaska Airlines were the third and fifth (fourth and fifth) largest U.S. carriers by number of passengers (by fleet size). In contrast, American Airlines, Delta Air Lines, and United Airlines — the top-three U.S. carriers by fleet size — all underwent bankruptcy or restructuring after 2000, holding their initial public offerings (IPOs) in 2013, 2007, and 2006, respectively.

Table 2: Summary statistics on excess stock returns for aviation and related industries

Aviation Industry	Min.	Median	Mean	Max.	Var.	Std.
World Airline Index	−17.26	−0.19	0.01	21.20	16.16	4.02
Alaska Airlines	−31.07	0.25	0.54	42.97	89.91	9.48
Southwest Airlines	−25.23	0.75	1.25	39.15	85.22	9.23
Lufthansa Group	−23.50	−0.23	0.17	27.13	47.28	6.88
Air France-KLM	−59.74	−0.81	0.51	125.70	195.68	13.99
Related Industries	Min.	Median	Mean	Max.	Var.	Std.
World Hotel Index	−15.88	0.11	0.14	21.30	13.57	3.68
World Travel & Tourism Index	−19.91	−0.14	0.10	29.94	25.77	5.08

Note: Summary statistics based on arithmetic excess returns for February 1974 through December 2019

as additional candidates for hedging against exogenous oil price fluctuations.

The monthly stock price data are available from DS starting in January 1973 and enter the structural VAR model in terms of *excess returns*, i.e. as the difference between month-on-month changes in the relevant stock price or index and the corresponding market-wide index, which we also extract from DS for consistency.[11] We consider excess returns in order to identify any hedging potential of investing in airlines and related industries *above and beyond* a broad global or national stock market index, whereas the conditional comovement between real oil prices and real stock returns alone is uninformative about whether investing in a particular industry offer more or less hedging opportunities than investing in a broad market index.

Table 2 reports summary statistics on the monthly excess stock returns of individual airlines and selected industry indices. It is important to note that the structural VAR in (1) is estimated separately for each measure of excess returns.

[11] Alternatively, we could have relied on a representative index for each market such as the MSCI World and the S&P 500, for example. However, representative and consistent stock market indices for Germany (e.g. MDAX) and France (e.g. CAC Mid 60) are only available starting in 1996 and 2005, respectively. Visual comparison of the DS World and U.S. Market Index with the MSCI World and the S&P 500, respectively, suggests that these measures are virtually identical.

3 Methodology

In this section, we present the details of our econometric methodology and specify the prior distributions for the estimated structural parameters.

3.1 Structural VAR model

We are interested in the comovement of oil prices and stock returns in the aviation industry following economically interpretable oil supply and demand shocks. For this purpose, we augment the 4-equation Bayesian SVAR model of the global oil market in Baumeister and Hamilton (2019) by a fifth equation for excess stock returns, i.e. the returns on airline or related industry stocks relative to the returns on a broad market index. The extended structural model, which contains thus a global oil market block and a stock market block, may be parameterized as follows:[12]

$$
\begin{aligned}
q_t &= \alpha_{qy} y_t + \alpha_{qp} p_t + b_1' x_{t-1} + u_{1t}^*, \\
y_t &= \alpha_{yq} q_t + \alpha_{yp} p_t + b_2' x_{t-1} + u_{2t}^*, \\
q_t &= \beta_{qy} y_t + \beta_{qp} p_t + \Delta i_t^* + b_3' x_{t-1} + u_{3t}^*, \\
\Delta i_t^* &= \psi_1^* q_t + \psi_2^* y_t + \psi_3^* p_t + b_4' x_{t-1} + u_{4t}^*, \\
r_t &= \gamma_{rq} q_t + \gamma_{ry} y_t + \gamma_{rp} p_t + \gamma_{r\Delta i} \Delta i_t^* + b_5' x_{t-1} + u_{5t}^*,
\end{aligned}
\tag{1}
$$

where the first equation determines the quantity of crude oil *supplied* in month t, q_t, as a function of real economic activity, y_t, and the real price of crude oil, p_t, in the same month, while u_{1t}^* denotes a structural oil supply shock. The second equation models world industrial production in month t as a contemporaneous function of the quantity and the real price of crude oil, while u_{2t}^* denotes a structural shock to global real economic activity. The third equation determines the quantity of crude oil *demanded* in month t as a contemporaneous

[12] For the sake of readability, we follow closely the notation in Baumeister and Hamilton (2019).

function of real economic activity and the real price of crude oil, while u_{3t}^* denotes a structural oil demand shock. Finally, Δi_t^* denotes the change in world crude oil inventories, modeled as a contemporaneous function of the quantity of oil supplied, world industrial production, and the real price of crude oil, while u_{4t}^* denotes a structural oil inventory demand shock.

To the global oil market block, we append the fifth equation, which models excess stock returns in month t, r_t, as a contemporaneous function of the quantity of crude oil supplied, world industrial production, and the real price of oil, while u_{5t}^* denotes a structural shock to excess stock returns.

The structural model in (1) implies that changes in inventories above the ground affect crude oil production and industrial production within the same month only through their effect on the real price of oil. Similarly, we assume that excess stock returns are not affected directly by changes in inventories except through their immediate effect on the oil price (i.e. $\gamma_{r\Delta i} = 0$). At the same time, each variable may be affected by *past* realizations of the vector of endogenous variables, $\mathbf{x}_{t-1} = [\mathbf{y}_{t-1}, \dots, \mathbf{y}_{t-p}]$, where $\mathbf{y}_t = (q_t, y_t, p_t, \Delta i_t^*, r_t)'$. In line with the original paper, we set $p = 12$ in monthly data.

3.2 Measurement error

Recall from Section 2 that the available data on world crude oil inventories is incomplete and possibly measured with error. Following Baumeister and Hamilton (2019), we therefore allow for a measurement error in oil inventories that is assumed to be serially uncorrelated and uncorrelated with the vector of structural shocks, $\mathbf{u}_t^*$. Specifically, changes in crude oil inventories observed in the data, Δi_t, correspond to a fraction of actual inventory changes, Δi_t^*, and are contaminated by the measurement error e_t. Formally,

$$\Delta i_t = \chi \Delta i_t^* + e_t. \tag{2}$$

Substituting for Δi_t^* in the third and fourth equation of (1), we may rewrite the structural model in terms of observables as

$$
\begin{aligned}
q_t &= \alpha_{qy} y_t + \alpha_{qp} p_t + \mathbf{b}_1' \mathbf{x}_{t-1} + u_{1t}^*, \\
y_t &= \alpha_{yq} q_t + \alpha_{yp} p_t + \mathbf{b}_2' \mathbf{x}_{t-1} + u_{2t}^*, \\
q_t &= \beta_{qy} y_t + \beta_{qp} p_t + \chi^{-1} \Delta i_t + \mathbf{b}_3' \mathbf{x}_{t-1} + u_{3t}^* - \chi^{-1} e_t, \\
\Delta i_t &= \chi \psi_1^* q_t + \chi \psi_2^* y_t + \chi \psi_3^* p_t + \mathbf{b}_4' \mathbf{x}_{t-1} + \chi u_{4t}^* + e_t, \\
r_t &= \gamma_{rq} q_t + \gamma_{ry} y_t + \gamma_{rp} p_t + \mathbf{b}_5' \mathbf{x}_{t-1} + u_{5t}^*.
\end{aligned}
\tag{3}
$$

Following Baumeister and Hamilton (2019), we simplify further the structural model in (3) by assuming that world industrial production affects world crude oil production within the same month only through its effect on the oil price, and vice versa, i.e. $\alpha_{qy} = \alpha_{yq} = 0$, and that world industrial production affects changes in crude oil inventories within the same month only through its effects on oil prices and production, i.e. $\psi_2 = 0$. In matrix notation, the above system of simultaneous equations thus reduces to the SVAR model

$$
\mathbf{A} \mathbf{y}_t = \mathbf{B} \mathbf{x}_{t-1} + \mathbf{u}_t, \tag{4}
$$

where

$$
\mathbf{A} = \begin{bmatrix} 1 & 0 & -\alpha_{qp} & 0 & 0 \\ 0 & 1 & -\alpha_{yp} & 0 & 0 \\ 1 & -\beta_{qy} & -\beta_{qp} & -\chi^{-1} & 0 \\ -\psi_1 & 0 & -\psi_3 & 1 & 0 \\ -\gamma_{rq} & -\gamma_{ry} & -\gamma_{rp} & 0 & 1 \end{bmatrix}, \qquad \mathbf{u}_t = \begin{bmatrix} u_{1t}^* \\ u_{2t}^* \\ u_{3t}^* - \chi^{-1} e_t \\ \chi u_{4t}^* + e_t \\ u_{5t}^* \end{bmatrix}, \tag{5}
$$

and $\mathbf{B}$ subsumes the coefficient matrices on the lagged vector of endogenous variables.

It is important to note that the structural model in (3) implies that the oil market block is predetermined with respect to the stock market block. The block-recursive structure is a common assumption in the literature (see, e.g., Kilian and Park, 2009) and motivated by the finding in Kilian and Vega (2011) that nominal oil prices are not affected by news about U.S. macroeconomic conditions at the daily and monthly frequency.

The focus on *excess returns* arguably makes the exclusion restrictions in the rightmost column of matrix $\mathbf{A}$ less restrictive than when modeling the returns on a broad stock market index (see, e.g., Kilian and Park, 2009; Güntner, 2014). It merely requires that shocks to airline stock returns above and beyond a broad stock market index affect neither oil prices and production nor global real economic activity *within the same month*, effectively presuming that contemporaneous causality runs from oil prices to airline excess returns rather than vice versa.

3.3 Prior distributions

In light of the block-recursive structure of the model in (3), the economic rationale for specifying the Bayesian priors for the structural parameters in the global oil market block is not affected by our extension. Hence, we closely follow Baumeister and Hamilton (2019) in choosing the prior distributions for the matrix of contemporaneous coefficients, $\mathbf{A}$, for the matrix of structural variances, $\mathbf{D}|\mathbf{A}$, and for the lagged structural coefficients, $\mathbf{B}|\mathbf{A}, \mathbf{D}$, which are therefore relegated to Table A.2 in the appendix. What remains to be specified are the prior distributions of the parameters in the stock market block of matrix $\mathbf{A}$, which govern the contemporaneous relationships between excess stock returns and world crude oil production, world industrial production, and the real price of crude oil, respectively.

Given that these contemporaneous relationships are ex ante ambiguous and at the heart of our study, we specify relatively uninformative and symmetric priors for γ_{rq}, γ_{ry}, and γ_{rp}, assuming a symmetric Student-t distribution centered around 0 with scale parameter 1 and 3 degrees of freedom (see also Aastveit et al., 2021). It is important to note that we do *not* restrict the sign of these coefficients. Instead, we hope that the data are sufficiently

Table 3: Prior distributions for contemporaneous coefficients in stock market block of **A**

Parameter	Economic meaning	Distribution	Location	Scale	D.o.f.
γ_{rq}	Sensitivity to world crude oil production	Student t	0	1	3
γ_{ry}	Sensitivity to world industrial production	Student t	0	1	3
γ_{rp}	Sensitivity to real price of crude oil	Student t	0	1	3

Note: The complete prior distributions are summarized in Table A.2 in the appendix and in Figure 3.

informative about the contemporaneous relationships of excess stock returns with world oil production, industrial production, and the real price of crude oil. The prior distributions are summarized in Table 3 and plotted as the solid red lines in the bottom panels of Figure 3, together with the prior distributions for the structural parameters already estimated in Baumeister and Hamilton (2019).

4 Empirical Results

In this section, we present and discuss our empirical results, starting with the posterior distributions of the estimated structural parameters. We then investigate the comovement of airline stock returns with real oil prices based on their impulse responses to a typical oil supply and demand shock, respectively, as well as based on the historical decomposition of fluctuations in oil price growth and excess stock returns.

4.1 Posterior distributions

Figure 3 plots the posterior distributions of the estimated structural parameters based on 2,000,000 iterations of the Metropolis-Hastings (MH) algorithm, where the first 1,000,000 draws are discarded as a burn in, against the prior distributions summarized in Tables 3 and A.2. Despite our extension of the structural model by one equation and of the sample period by three years, i.e. 2017:1–2019:12, the histograms of the posterior distributions in the upper

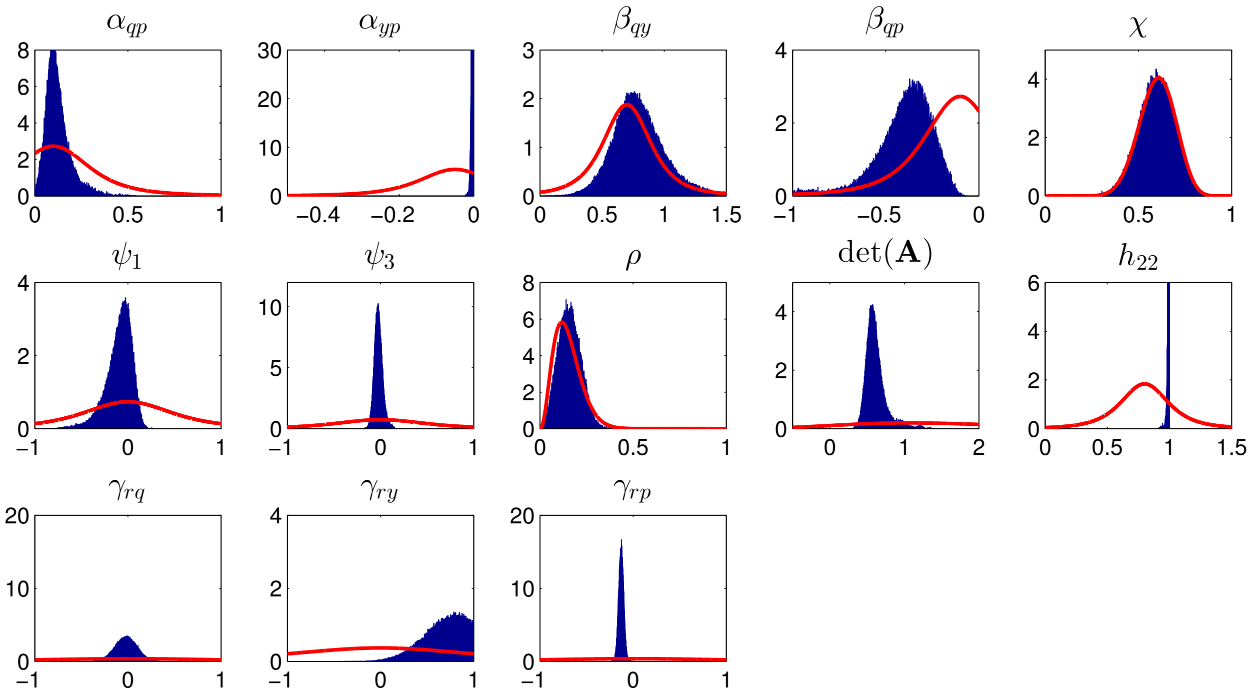


Figure 3: Prior (solid red lines) and posterior (blue histograms) distributions of the contemporaneous coefficients in $\mathbf{A}$ for the baseline 5-variable model in (3)

Note: Posterior distributions of parameters based on 1,000,000 MH iterations after 1,000,000 burn-in draws

two rows are virtually identical with those in Figure 7 of Baumeister and Hamilton (2019).[13]

According to the additional histograms in the third row, the posterior distribution of the contemporaneous relationship between excess returns on the World Airline Index (WAI) and world oil production, γ_{rq}, is largely symmetric and centered around 0, whereas that of the contemporaneous relationship with world industrial production, γ_{ry}, is shifted to the right, and that of the contemporaneous relationship with the real price of oil, γ_{rp}, is shifted to the left relative to their symmetric prior distributions.[14] Moreover, the informativeness of the data about the parameters in the stock market block, as measured by the difference between the prior and posterior distributions, varies between parameters.

[13]Figures A.2 and A.3 in the appendix show the trace plots and autocorrelation functions of the posterior parameter draws, which suggest that all parameters have converged after discarding the first 1,000,000 draws.

[14]The posterior median estimates of γ_{ry} and γ_{rp} are $+.811$ and $-.128$, while that of γ_{rq} is $-.021$.

4.2 Impulse response analysis

While the posterior distributions in Figure 3 are informative about the structural model in (3) and its matrix representation in (4), they must *not* be interpreted as the response to an oil supply, global economic activity, oil consumption demand or oil inventory demand shock, respectively. Instead, we may readily compute the impulse response function of each of the endogenous variables in $\mathbf{y}_t$ to each of the structural shocks in $\mathbf{u}_t$ at horizon s as

$$\frac{\partial \mathbf{y}_{t+s}}{\partial \mathbf{u}_t'} = \frac{\partial \mathbf{y}_{t+s}}{\partial \epsilon_t'} \frac{\partial \epsilon_t'}{\partial \mathbf{u}_t'} = \mathbf{\Psi}_s \mathbf{A}^{-1}, \tag{6}$$

where the reduced-form impulse response functions in $\mathbf{\Psi}_s$ are given by the first n rows and columns of $\mathbf{F}^s$, and the companion matrix $\mathbf{F}$ is given by

$$\mathbf{F} = \begin{bmatrix} \mathbf{\Phi}_1 & \mathbf{\Phi}_2 & \cdots & \mathbf{\Phi}_{p-1} & \mathbf{\Phi}_p \\ \mathbf{I}_n & \mathbf{0} & \cdots & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_n & \cdots & \mathbf{0} & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{I}_n & \mathbf{0} \end{bmatrix}, \qquad \mathbf{\Phi} = \mathbf{A}^{-1}\mathbf{B}, \qquad \epsilon_t = \mathbf{A}^{-1}\mathbf{u}_t.$$

Due to the qualitative and quantitative similarity of the impulse response functions in the global oil market block with those in Baumeister and Hamilton (2019), we focus here on the responses of WAI excess returns to each of the structural shocks and defer the complete set of impulse response functions to Figure A.4 in Appendix A.5.[15]

[15] It is important to note that none of the variables in the oil market block responds significantly (at the 5% level) to an airline excess returns shock in the rightmost column of Figure A.4.

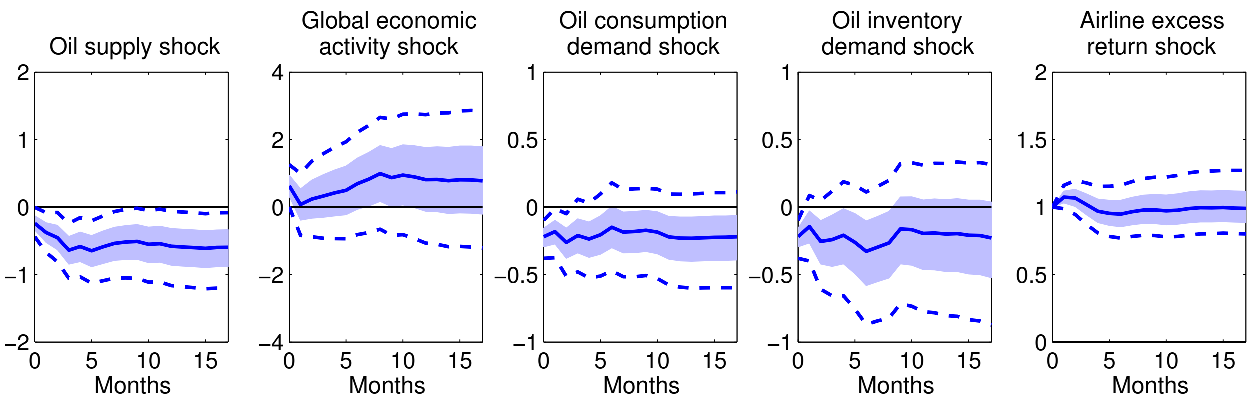


Figure 4: Impulse response functions of WAI excess returns for the baseline model in (3)
Note: Bayesian posterior medians (solid lines) with 68 percent (shaded areas) and 95 percent (broken lines) posterior credible sets based on 1,000,000 MH iterations after 1,000,000 burn-in draws

4.2.1 Structural impulse responses

Figure 4 plots the posterior median response of WAI excess returns to each of the structural shocks together with 68 and 95% posterior credible sets, where the oil market shocks are normalized such that they raise the real price of oil. On average over the sample period, a negative oil supply shock, which raises the real oil price by about 2% on impact and 3.3% after two months, lowers cumulated WAI excess returns by about .24% on impact and .64% after three months. Both the increase in the real price of oil and the reduction in WAI excess returns are statistically significant at the 5% level for at least 18 months.

In response to a global economic activity shock, which raises the real oil price by 1.3% on impact and 6% after six months, cumulated WAI excess returns increase by about .6% on impact and 1% after eight months. In this case, however, the impulse response function of WAI excess returns is statistically significant only at the 32% level or less, indicating that the shock affects current and expected future airline profits in different directions. On the one hand, higher oil prices raise operating costs and lower thus airline profits. On the other hand, increased economic activity likely raises global demand for transportation and travel services as well as airline profits. Overall, the WAI seems to perform somewhat better than a broad comparison index, albeit any differences are hardly statistically significant.

A typical oil consumption demand shock, which raises the real price of oil by 1.7% on impact and 2.5% after two months, lowers cumulated WAI excess returns by .22% on impact and .26% after two months. While the pointwise median response remains negative for the subsequent 18 months, from period three onwards, it is statistically significant only at the 32% level. In this case, the adverse effects of higher oil prices apparently exceed any positive effect on current and expected future airline profits, at least qualitatively.

Consider next the impulse response of the WAI to a positive oil inventory demand shock, which raises the real price of oil by 1.7% on impact and 2.4% after six months. In this case, cumulated WAI excess returns fall by .22% on impact and .33% after six months, albeit only the impact response is statistically significant at the 5% level.

The impact response to an airline excess return shocks is normalized to one. Accordingly, the median impulse response function of cumulated WAI excess returns hovers around unity for the subsequent 18 months. From Figure A.4, the shock also *lowers* the real price of oil by about .4% after five months, which is statistically significant at the 5% level.

4.2.2 Conditional comovement of impulse responses

Figure 5 illustrates the comovement of impulse response functions for real oil prices and cumulated WAI excess returns conditional on each of the structural shocks in the vector $\mathbf{u}_t$, effectively combining the information in the third and fifth row of Figure A.4.[16]

Following a typical negative oil supply shock, real oil prices increase and cumulated WAI excess returns fall. Accordingly, their conditional comovement is negative and statistically significant for at least 18 months. In contrast, a typical positive shocks to global economic activity raises both real oil prices and WAI excess returns on impact, whereas their conditional comovement is statistically insignificant even at the 32% level, from month one onwards. Oil consumption and oil inventory demand shocks induce qualitatively and quantitatively

[16]For each of the 1,000,000 draws after burn in, we compute the product of the impulse response functions for real oil prices and WAI excess returns and extract pointwise medians and posterior credible sets based on their *model-specific* conditional comovement. This is crucial in order to avoid mixing impulse responses from different model draws.

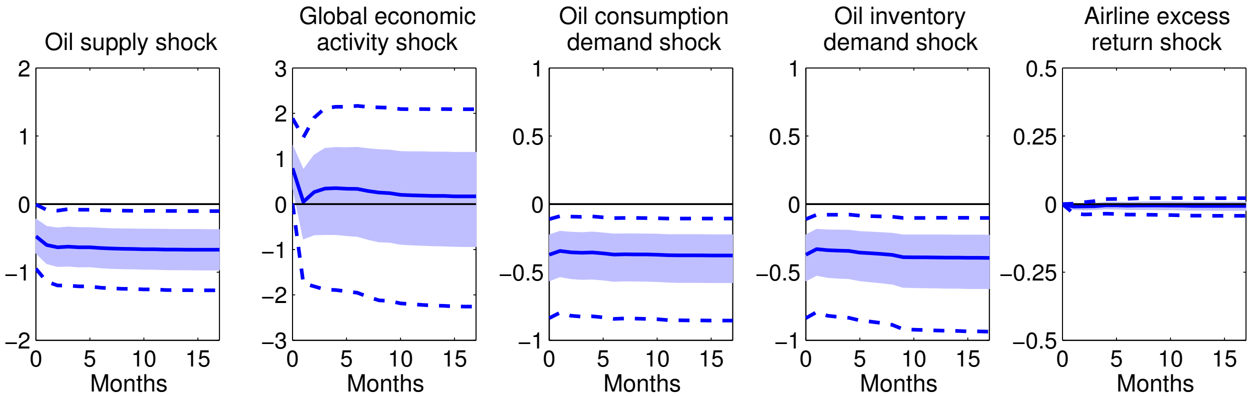


Figure 5: Conditional comovement of impulse response functions of real oil price growth and WAI excess returns

Note: Bayesian posterior medians (solid lines) with 68 percent (shaded areas) and 95 percent (broken lines) posterior credible sets based on 1,000,000 MH iterations after 1,000,000 burn-in draws

very similar comovement of real oil prices with WAI excess returns, i.e. negative and highly statistically significant for at least 18 months after either shock. Finally, the rightmost panel of Figure 5 illustrates that a negative impulse response of real oil prices and a positive impulse response of cumulated WAI excess returns to a typical positive airline excess return shock does not necessarily imply hedging potential. The conditional comovement of the two variables is quantitatively small and statistically insignificant, suggesting that the respective pointwise median responses in Figure A.4 sets are *not* based on the same model draws.

We therefore conclude that, on average over the sample period, airline investments come along with a hedging benefit against exogenous fluctuations in oil prices, in particular due to oil supply, oil consumption demand, and oil inventory demand shocks.

4.3 Historical decomposition analysis

While the impulse response analysis in the previous section illustrates the effects of each structural shock *on average over the sample period*, it does not reveal how much each shock contributed to historical fluctuations of the endogenous variables at a specific point in time. For this purpose, Figures A.5 and A.6 in Appendix A.6 plot the cumulative effect of each

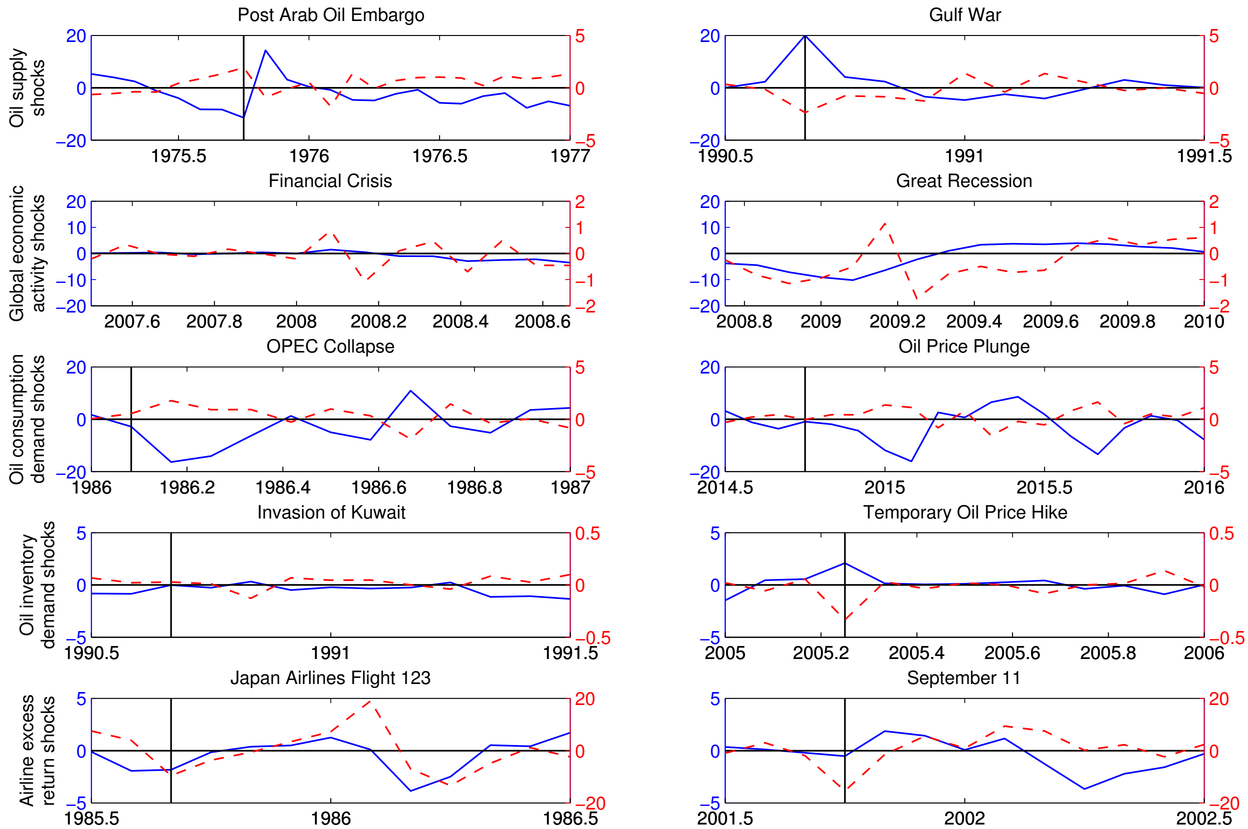


Figure 6: Historical decomposition of real oil price growth and WAI excess returns during selected historical episodes

Note: Pointwise median contribution of structural shocks to real oil price growth (solid line, left axis) and WAI excess returns (broken line, right axis) based on 250,000 MH iterations after 1,000,000 burn-in draws. Historical decompositions for the entire sample period are shown in Figures A.5 and A.6 in the appendix.

structural shock on real oil price growth and WAI excess returns, respectively, against the historical data.[17]

4.3.1 Historical episodes

Given our focus on the hedging benefit of airline investments, each row of Figure 6 plots the pointwise median contribution of the respective structural shock to real oil price growth and WAI excess returns *during selected historical episodes*. Airline investments may attenuate fluctuations in oil export revenues, if (and only if) current and expected future

[17]For the common sample period, Figure A.5 virtually replicates the results in Figure 9 of Baumeister and Hamilton (2019). We abstain from plotting the cumulative effect of measurement error in the oil inventory equation on either variable, as it is largely unsystematic and has little economic interpretation.

profits comove negatively with real oil prices.

Consider the first row, which depicts the comovement of real oil price growth and WAI excess returns due to oil supply shocks after the Arab-Israeli War and the Arab Oil Embargo and during the Persian Gulf War of 1990–1991, respectively. Following a period of easing supply conditions, such as the replacement of a scheduled 5 percent drop by the promise of a 10 percent hike in OPEC production, the ending of restrictions on oil exports to the U.S. and other oil importing economies, and Iraq's announcement to raise production capacities to 3,500 tbpd by 1975 and 6,000 tbpd by 1981, on September 24 of 1975, OPEC oil ministers announced a 15 percent increase in government revenues per barrel effective October 1.[18] The top left panel illustrates that negative oil supply shocks put substantial upward pressure on real oil prices in October 1975 (from −11.4 to +14.3). Concurrently, the cumulative effect on WAI excess returns dropped by about 2.8 percentage points (from 1.91 to −.926).

Similarly, the invasion of Kuwait by Iraqi forces in August 1990 and the ensuing military occupation, which brought oil production in the two countries to a near halt, raised real oil prices by 20% in August and another 4% in September. At the same time, the cumulative effect on WAI excess returns dropped to −2.36 in August and −.776 in September. During both episodes, oil supply shocks induced negative comovement of real oil prices and the WAI, suggesting a hedging benefit above and beyond the DS World Stock Index.

In contrast, there is no evidence of systematic (positive or negative) comovement between real oil price growth and WAI excess returns due to global economic activity shocks during the Financial Crisis or the Great Recession in the second row of Figure 6. While the effect on real oil prices follows a clear downward trend prior to the bankruptcy of Lehman Brothers in September 2008, the contribution to the WAI fluctuates between positive and negative values. Similarly, the right panel suggests that the contribution of global economic activity shocks to the recovery of real oil prices during the Great Recession was not systematically correlated with the effect on WAI excess returns, at least at the monthly frequency.

[18] Moreover, Kuwait and Venezuela reached an agreement with foreign oil companies, while Iraq completed the nationalization of its oil industry in the third quarter of 1975.

Instead, we find evidence of negative conditional comovement in the cumulative effect of oil consumption demand shocks during two episodes of falling oil prices in the mid-1980s and mid-2010s.[19] In either panel, the contribution to historical fluctuations in WAI excess returns virtually mirrors that to real oil price growth, suggesting a hedging benefit of airline investments.

The same qualitative pattern, albeit on a smaller scale, holds for oil inventory demand shocks prior to the invasion of Kuwait by Iraqi forces in August 1990 and in March 2005, when oil prices reached an intermediate high after falling for several months in late 2004 and early 2005. The corresponding historical decompositions in the fourth row of Figure 6 illustrate that the mildly positive effect on real oil price growth in the left panel coincides with a clear negative effect on WAI excess returns in October 1990, while the positive and negative spike, respectively, in March 2005 dominates the decomposition in the right panel. During both episodes, the cumulative effects of oil inventory demand shocks on real oil prices and the WAI are virtually mirrored across the horizontal axes.

Consider finally the bottom row of Figure 6, which plots the contribution of airline excess return shocks to historical fluctuations in real oil prices and the WAI around two key events in aviation history. On August 12 of 1985, Japan Airlines Flight 123 crashed near Mount Takamagahara in Gunma Prefecture, 32 minutes after takeoff from Tokyo's Haneda Airport on route to Osaka International Airport. The Boeing 747SR-46, configured with increased economy-class seating, was carrying 15 crew members and 509 passengers, only four of which survived the crash and wait time for rescue in the mountain region.[20] The bottom left panel in Figure 6 illustrates that the effect on WAI excess returns dropped sharply in August 1985 and peaked again only in January 1986, when several U.S. airlines reported unexpectedly

[19] Following repeated deviations of OPEC members from their cartel production quotas in the early 1980s, Saudi Arabia tried to stabilize oil prices by cutting back domestic production. When this strategy failed and the country incurred large losses, Saudi Arabia suspended any restrictions on domestic production by end of 1985. See Baumeister and Kilian (2016) for the reasons behind the oil price decline after August 2014.

[20] The crash of Japan Airlines Flight 123 remains the deadliest single-aircraft accident and August 1985 the deadliest month in aviation history. Japan's Aircraft Accident Investigation Commission officially concluded that the aircraft suffered a sudden decompression twelve minutes into the flight due to a faulty repair by Boeing technicians following a previous tailstrike incident while landing at Osaka Airport in 1978.

high profits for 1985Q4.[21] While the effect on real oil price growth was negative already prior to the accident, it recovered rather than declining further in August and September of 1985. Conversely, the contribution to real oil prices fell in January and February of 1986, exactly when that to the WAI peaked. Similarly, we do not observe a systematic comovement in the cumulative effects on real oil price growth and WAI excess returns around September 2001, when islamist terrorists hijacked American Airlines Flight 11 and United Airlines Flight 175 on route from Boston to Los Angeles and crashed both planes into World Trade Center, killing 20 crew members, 137 passengers, and an estimated 2,500 victims on the ground.[22] In the bottom right panel, we find no evidence of a systematic comovement in the cumulative effects on real oil price growth and WAI excess returns. While the contribution to the WAI dropped sharply in September 2001, oil prices were barely affected. When the contribution to real oil prices dropped by close to 4% in March 2002, however, that to the WAI also fell from +10% to zero. On the contrary, the cumulative effect on the WAI fluctuated around zero during 2002:3–2002:6, while that on the real oil price fully recovered.

4.3.2 Conditional correlation of HDs

The historical decompositions in Figure 6 suggest that oil supply, oil consumption demand, and oil inventory demand shocks induce negative comovement between real oil price growth and WAI excess returns *during selected historical episodes*, whereas this is not the case for shocks to global economic activity and airline excess returns. Figure A.7 in Appendix A.7 plots the product of the contributions of each structural shock to historical fluctuations in real oil prices and the WAI based on 250,000 accepted models after 1,000,000 burn-in draws and illustrates that our previous findings are *not* specific to the selected historical episodes.

[21]For example, AMR Corporation, the parent company of American Airlines Inc., reported a record net income of $345.8 million, or $5.94 per share, for the year 1985 (Associated Press, 1986).

[22]On the same day, American Airlines Flight 77 on route from Washington, D.C. to Los Angeles was hijacked by five Saudi men affiliated with al-Qaeda and crashed deliberately into the Pentagon in Arlington County, Virginia, killing 6 crew and 58 passengers on board as well as 125 in the building. A fourth plane, United Airlines Flight 93 on route from Newark to San Francisco crashed into a field near Shanksville, Pennsylvania, when passengers tried to take back control from four Al-Qaeda hijackers, killing all 33 passengers and 7 crew. In total, the September 11 terrorist attacks cost close to 3,000 lives.

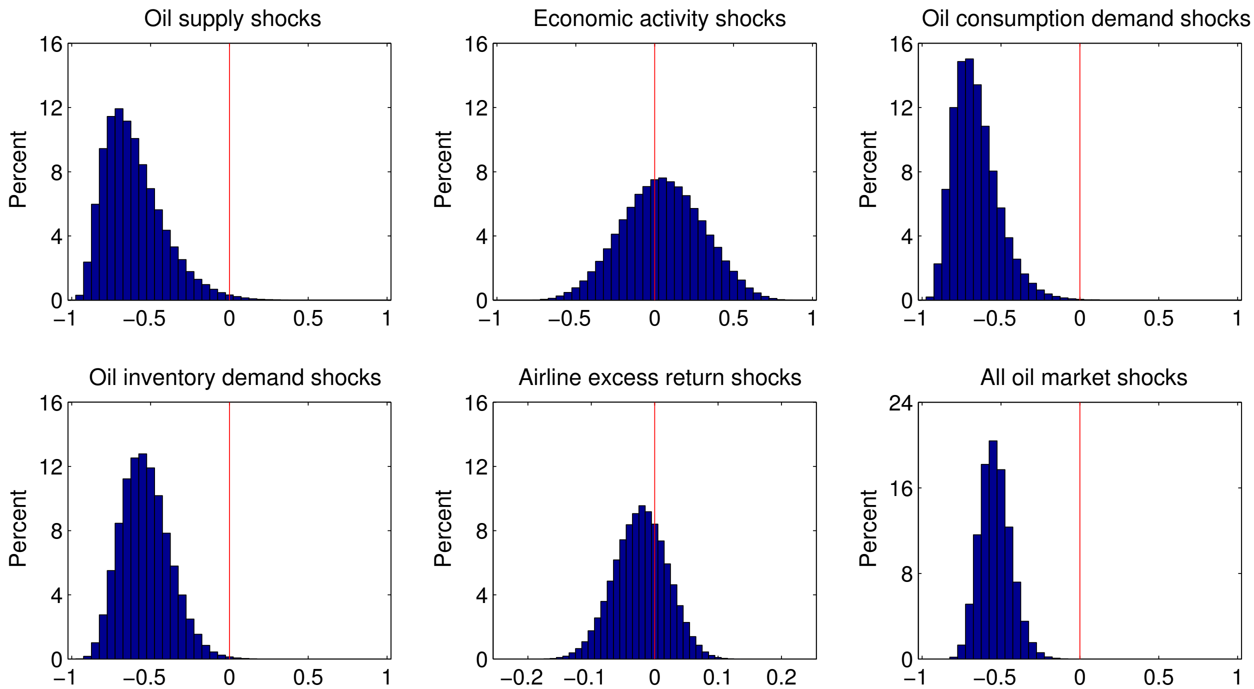


Figure 7: Conditional correlations of cumulative contributions to historical oil price growth and WAI excess returns

Note: Histograms of correlation coefficients between real oil price growth and WAI excess returns conditional on each structural shock based on 250,000 MH iterations after 1,000,000 burn-in draws

Instead, the pointwise median products and posterior credible sets display negative spikes conditional on oil supply, oil consumption demand, and oil inventory demand shocks, while there is no obvious pattern of conditional comovement for shocks to global economic activity and airline excess returns.

Figure 7 summarizes related information in the histograms of the conditional correlation coefficients for the same 250,000 model draws, where each coefficient reflects the correlation of the cumulative effects on real oil price growth and WAI excess returns for a given structural shock and model draw.[23] The top left, top right, and bottom left panels strongly suggest that, on average over the sample period, oil supply, oil consumption demand, and oil inventory demand shocks induce negative comovement between real oil price growth and WAI

[23] In contrast to the *pointwise* medians and posterior credible sets in Figure A.7, the conditional correlation coefficients in Figure 7 are *model-specific* throughout the entire sample period and thus not affected by the critique in Kilian and Inoue (2013).

excess returns in the majority of accepted models. The posterior median of the conditional correlation coefficient is $-.64$, $-.68$, and $-.54$, respectively, while only a small fraction of model draws implies a positive conditional correlation between real oil price growth and WAI excess returns. The posterior distributions of conditional correlation coefficients for global economic activity and airline excess return shocks are instead broadly symmetric around zero, with medians of $+.05$ and $-.02$.

In order to gauge whether the conditional comovement in the historical decomposition of real oil prices and the WAI is dominated by oil supply and demand shocks, which induce a clear negative correlation, or global economic activity shocks, which induce a positive albeit statically insignificant correlation, the bottom right panel in Figure 7 plots the posterior distribution of the correlation coefficients conditional on *all four* structural oil market shocks. In light of a posterior median of $-.54$ and virtually all of the mass left of the vertical line at zero, real oil price growth and WAI excess returns are systematically negatively correlated conditional on the historical composition of oil market shocks. Accordingly, we conclude that investments in Datastream's World Airline Index offer a hedging benefit against exogenous fluctuations in crude oil prices above and beyond Datastream's World Market Index.

4.4 Individual airline excess returns

The claim in this study is that oil producers might enjoy a hedging benefit from airline investments. Rather than investing in a global airline index, however, OPEC member states in the Persian Gulf have established state-owned international airlines and major aviation hubs in the region. For this reason, Figure 8 depicts the impulse response functions of the excess returns of four individual airlines' stocks relative to a national stock market index. Due to the lack of publicly available data for any of the Persian Gulf carriers as well as the leading U.S. airlines by number of passengers and fleet size (i.e. American Airlines, Delta Air Lines, and United Airlines), we consider the next two closest U.S. airlines as well as German Lufthansa and Air France-KLM, for which consistent stock price data is available starting

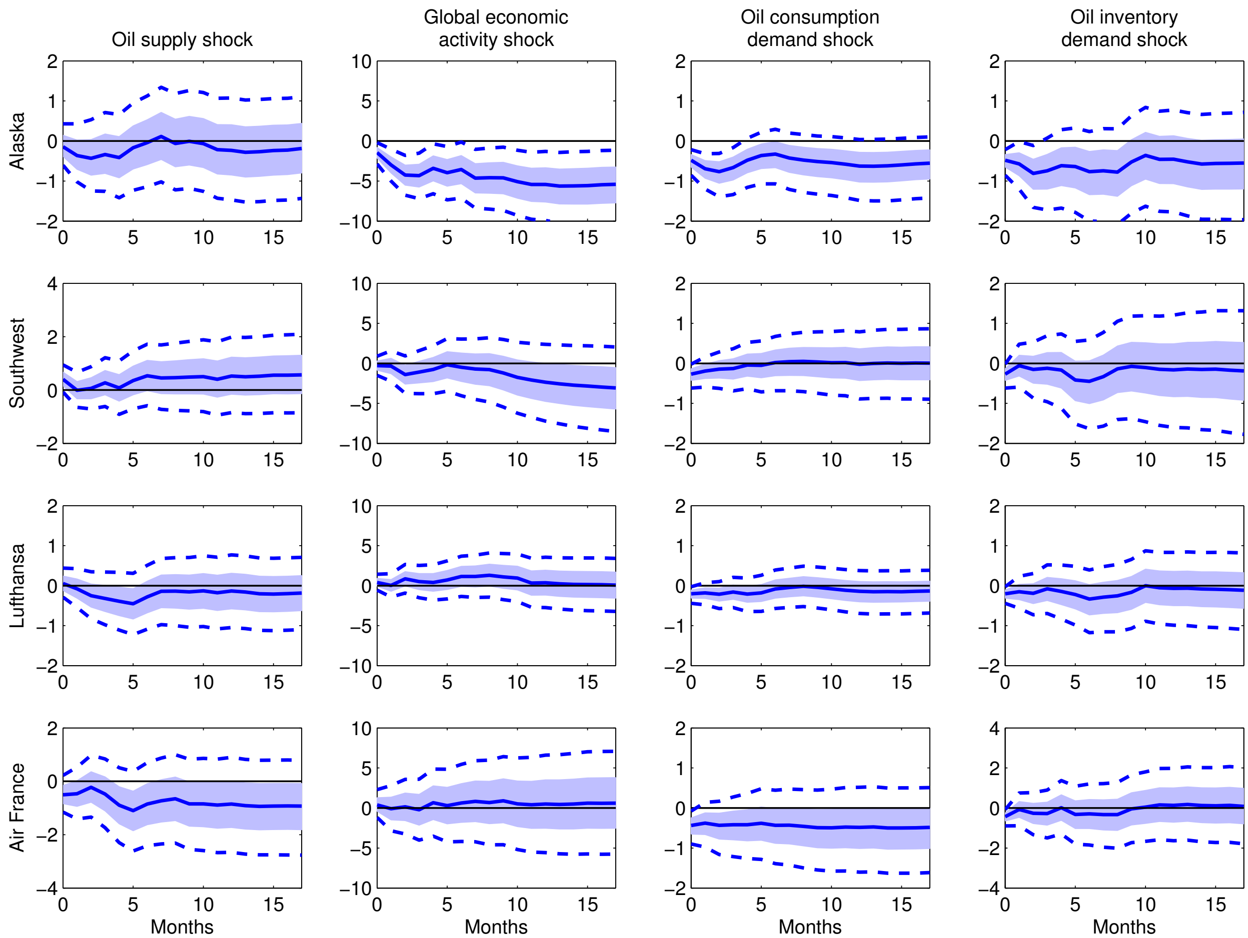


Figure 8: Impulse response functions of excess returns on individual airline stocks

Note: Bayesian posterior medians (solid lines) with 68 percent (shaded areas) and 95 percent (broken lines) posterior credible sets based on 1,000,000 MH iterations for each airline after 1,000,000 burn-in draws

in January 1973.[24]

Figure 8 illustrates some heterogeneity in the impulse responses to the four structural oil supply and demand shocks. While excess returns on the stocks of Alaska Airlines, Lufthansa, and Air France-KLM fall after a typical negative oil supply shock, and the impulse response functions are statistically significant at the 32% level or higher, this is not the case for Southwest Airlines. Similar to the DS WAI, excess returns on Southwest Airlines, Lufthansa, and Air France-KLM do not respond significantly to a typical positive global economic activity shock, which raises the real price of crude oil. In contrast, excess returns on the

[24]All stock price and stock index data are obtained from Refinitiv Datastream (DS).

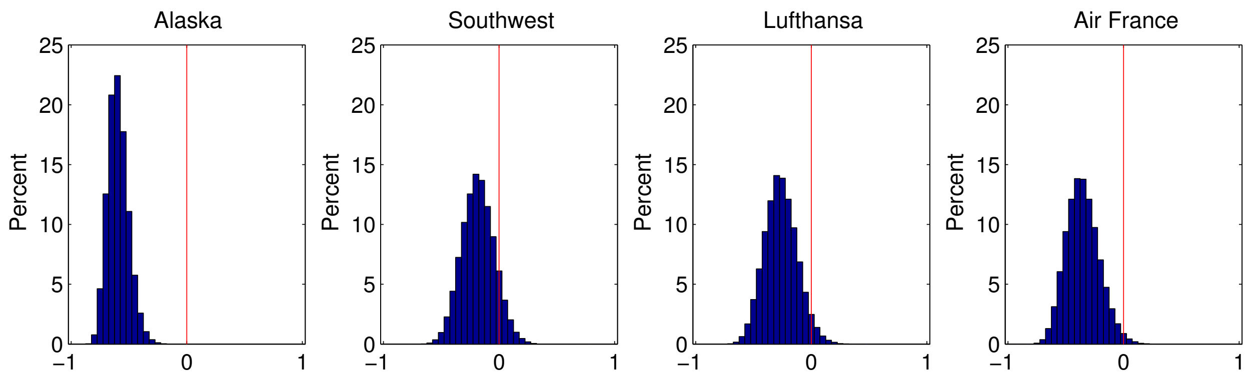


Figure 9: Conditional correlations of cumulative effects on oil price growth and individual airlines excess returns

Notes: Histograms of correlation coefficients between real oil price growth and excess returns on individual airline stocks conditional on *all* structural oil market shocks based on 100,000 MH iterations after 1,000,000 burn-in draws. Conditional correlations for each structural shock are plotted in Figure A.9 in the appendix.

stock of Alaska Airlines fall significantly at the 5% for at least 18 months following the shock. Alaska Airlines also displays the most pronounced and statistically significant response to a positive oil consumption demand and oil inventory demand shock, respectively, whereas the impulse response functions for the other three airlines are statistically significant (at the 5% level) only on impact.

While the responses of individual airlines' excess stock returns are consistent with our findings for the WAI, airline-specific characteristic also seem to play an important role. The data on jet fuel costs in Table 1 suggests that differences in the cost structure and business cyclicality, in particular between the two U.S. airlines and the European legacy carriers, might explain the heterogeneity of impulse response functions in Figure 8.

Figure 9 reveals that this heterogeneity carries over to conditional correlations in the historical decomposition of real oil price growth and individual airlines excess returns. Similar to the bottom right panel in Figure 7, the four structural oil market shocks *together* induce negative correlations between real oil prices and airline excess returns, although the degree and statistical significance varies by airline. While every single model draw implies a negative conditional correlation for Alaska Airlines, an increasing share of models implies a positive conditional correlation for Air France-KLM, Lufthansa, and Southwest Airlines, respectively.

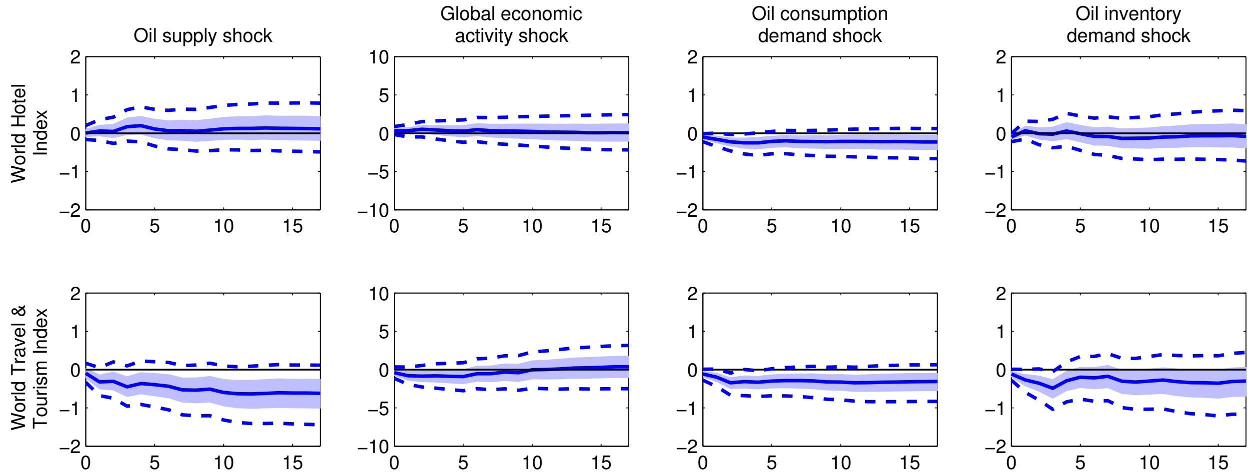


Figure 10: Impulse response functions of excess returns on Datastream World Hotel Index and World Travel & Tourism Index

Note: Bayesian posterior medians (solid lines) with 68 percent (shaded areas) and 95 percent (broken lines) posterior credible sets based on 1,000,000 MH iterations for each index after 1,000,000 burn-in draws

The corresponding median correlation coefficients are $-.595$, $-.353$, $-.258$, and $-.174$, all of which imply a hedging benefit of investing in individual airlines.

4.5 Hotel, travel & tourism

Another observation is that, while establishing international aviation hubs in the region, OPEC members in the Persian Gulf, in particular Dubai, have promoted the development of domestic tourism and hotel infrastructure. For this reason, we study the impulse response functions of the DS World Hotel Index (WHI) and World Travel & Tourism Index (WTTI), respectively, in the top and bottom row of Figure 10.

Similar to the WAI, excess returns on the WTTI relative to the DS World Market Index fall in response to each of the structural oil supply and demand shocks, suggesting substantial hedging potential against fluctuations in the real price of oil. The impulse response functions are statistically significant at the 32% level for oil supply and global economic activity shocks and at the 5% level for oil consumption demand and oil inventory demand shocks.

In contrast, excess returns on the WHI tend to increase in response to a typical negative

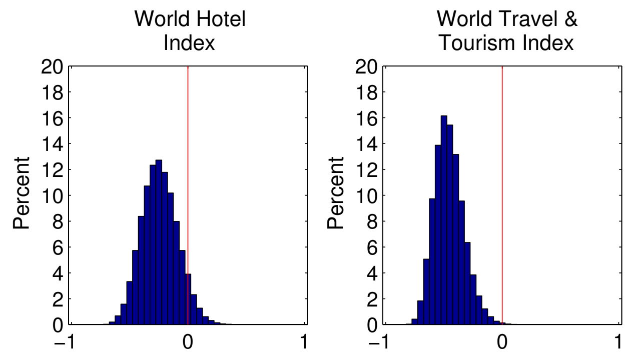


Figure 11: Conditional correlations of cumulative effects on oil price growth with WHI and WTTI excess returns for all oil market shocks

Notes: Histograms of correlation coefficients between real oil price growth and excess returns on DS World Hotel and World Travel & Tourism Index conditional on *all* structural oil market shocks based on 100,000 MH iterations after 1,000,000 burn-in draws. Conditional correlations for each structural shock are plotted in Figure A.11 in the appendix.

oil supply and positive global economic activity shock, fall in response to a positive oil consumption demand and hardly respond to an oil inventory demand shock. Note, however, that only the negative response to a typical oil consumption demand shock is statistically significant at the 5% level.

The comparison of impulse response functions in the top and bottom row of Figure 10 suggests that fluctuations in the real price of crude oil and its derivative products, which are a key input in transportation, drive the negative conditional comovement of WAI and WTTI excess returns with real oil prices in response to structural oil supply and demand shocks. For WHI excess returns, instead, this negative conditional comovement is confined to oil consumption demand shocks. It is therefore not surprising that the hedging benefit of the WTTI appears larger than that of the WHI. In the right panel of Figure 11, virtually all model draws imply a negative correlation of real oil price growth with WTTI excess returns conditional on *all four* structural oil market shocks, whereas a non-negligible share of model draws implies a positive correlation with WHI excess returns. The corresponding median correlation coefficients are $-.460$ and $-.241$, respectively, both of which indicate nontrivial hedging potential against exogenous fluctuations in the real price of oil due to structural oil supply and demand shocks.

5 Conclusion

Ownership of finite natural resources, such as crude oil reserves, is a blessing that comes along with major short- and long-term challenges. Sizeable historical volatility in the price of crude oil exposes oil-exporting countries to financial risks in the short run, while they rely on smooth oil revenues as a source of national income. At the same time, crude oil reserves are bound to be either exhausted or replaced by alternative energy sources and non-fossil fuels in the medium run. Given that fiscal policy rules do not seem to insulate the domestic economy from oil price shocks even in a resource-rich developed country, such as Norway (Bjørnland and Thorsrud, 2019), oil-exporting countries have a strong incentive to diversify the domestic economy and invest their oil wealth in alternative assets.

Owning close to half of the world's proven reserves, oil-exporting countries in the Persian Gulf are facing these challenges. During the past two decades, several of them have rapidly expanded the domestic travel and tourism industry. Drawing on massive financial resources and the installment of global aviation hubs in the region, state-owned Persian Gulf carriers gained sizeable market shares in a highly competitive environment. Besides the advantage of geographic location between Europe, Africa, and Asia, we argue that such investments come along with a hedging benefit, as jet fuel costs are a nontrivial share of operating expenses.

Building on the Bayesian structural VAR model of the global oil market in Baumeister and Hamilton (2019), we investigate the conditional comovement of real oil price growth with airline excess stock returns above and beyond a representative market index. Due to the lack of publicly available balance sheet or stock price data for any of the state-owned Persian Gulf carriers, we consider the Datastream (DS) World Airline Index (WAI) as a proxy for current and future expected profits in the global airline industry as well as the individual stocks of Alaska Airlines, Southwest Airlines, Lufthansa, and Air France-KLM, which were publicly listed throughout the entire sample period, 1974:2–2019:12. We then extend our analysis to the hotel and tourism sectors, which have recently undergone a rapid expansion in Persian Gulf countries, as well, and consider the impulse response functions and conditional correlations of the DS World Hotel Index and World Travel & Tourism Index.

We find that WAI excess returns decrease significantly in response to a typical negative oil supply, positive oil consumption demand, and positive oil inventory demand shock, all of which tend to raise the real price of crude oil. While WAI excess returns tend to increase in response to a positive global economic activity shock, the impulse response function is not statistically significant at conventional levels. On average over the sample period, oil supply, oil consumption demand, and oil inventory demand shocks thus induce negative conditional comovement between real oil price growth and airline excess returns, which is a prerequisite for any hedging benefit. Consistently, we find that oil supply, oil consumption demand, and oil inventory demand shocks cause negative comovement in the historical decompositions of real oil price growth and WAI excess returns during selected historical episodes, while this is not the case for global economic activity shocks or airline excess return shocks. Finally, we show that this negative comovement is not confined to the selected episodes, as virtually all model draws imply a negative correlation between real oil price growth and WAI excess returns conditional on the historical composition of structural oil supply and demand shocks. We therefore conclude that financial investments in the WAI offer a hedging benefit against exogenous fluctuations in real oil prices.

Our analysis of individual airlines reveals heterogeneity in the hedging potential across different shocks and carriers. While excess returns on the stock of Alaska Airlines comove negatively with real oil price growth in response to each of the structural oil supply and demand shocks, this is not the case for excess returns on the stocks of Southwest Airlines, Lufthansa, and Air France-KLM. Based on the historical composition of structural oil supply and demand shocks, during our sample period, an investment in Alaska Airlines consistently offers the largest hedging benefit. Similarly, we find stronger evidence for a hedging benefit in the impulse response functions and historical decomposition of the World Travel & Tourism Index relative to the World Hotel Index.

It is important to note that, by considering excess stock returns as a proxy for current and future expected airline profits, we measure the difference in returns from investing in the airline industry as opposed to a broad stock market index. Given that most constituents in the DS WAI, including the individual airlines under consideration, already engage in jet fuel hedging in order to reduce their exposure to fluctuations in crude oil prices (see, e.g., Carter et al., 2006; Jin and Jorion, 2006), our results are likely on the conservative side. The effects for state-owned Persian Gulf carriers, which might have limited access to or deliberately refrain from jet fuel hedging in global commodity markets, may well be larger.

The heterogeneity in our findings for individual airlines' stocks, in particular the response of Alaska Airlines' excess returns to structural oil supply and demand shocks, calls for further research on the fundamental determinants of airline profits and losses. In the meantime, this study provides empirical evidence that the decision of oil-exporting economies in the Persian Gulf to foster their domestic travel and tourism industry might help mitigate the unfavorable effects of oil price fluctuations on national income. This is important especially for countries that rely on a smooth stream of oil export revenues both in the short and in the long run.

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A Appendix

A.1 Datastream classification system

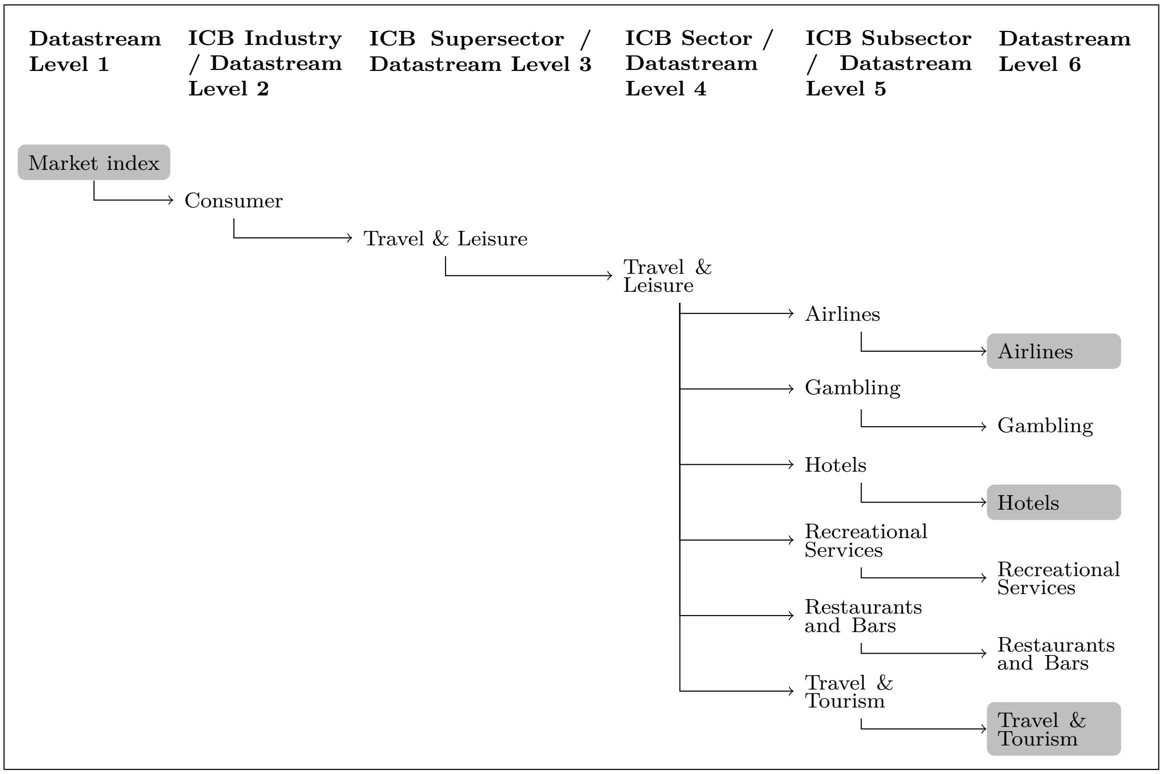

Figure A.1: Refinitiv Datastream (DS) equity index classification

Notes: The DS classification system is based on the Industry Classification Benchmark (ICB) jointly created by FTSE and Dow Jones. Relevant indices are shaded.

A.2 World Airline Index constituents

Table A.1: Datastream World Airline Index constituents and index weights

Airline Group	Country of origin	Market capitalization (in 1,000 US-$)	Index weight (in %)
Qantas Airways	Australia	6,653,275	2.30
Azul PN	Brazil	2,695,263	0.93
Air Canada Voting and Variable Voting	Canada	6,930,005	2.40
Exchange Income Corporation	Canada	1,151,235	0.40
Latam Airlines Group	Chile	1,560,084	0.54
Air China 'H'	China	16,925,288	5.86
China Eastern Airlines 'H'	China	12,437,826	4.30
China Southern Airlines 'H'	China	13,705,804	4.74
Croatia Airlines	Croatia	347,943	0.12
Finnair	Finland	1,156,794	0.40
Air France-KLM	**France**	**2,061,583**	**0.71**
Deutsche Lufthansa	**Germany**	**7,130,372**	**2.47**
Aegean Airlines CR	Greece	495,661	0.17
Interglobe Aviation	India	9,345,925	3.23
Ryanair Holdings	Ireland	21,684,758	7.50
ANA Holdings	Japan	11,701,682	4.05
Japan Airlines	Japan	9,841,758	3.41
Alia (Royal Jordanian Airlines)	Jordan	NA	NA
Hanjin KAL	South Korea	3,626,895	1.25
Korean Air Lines	South Korea	9,200,521	3.18
Jazeera Airways	Kuwait	453,843	0.16
AirAsia Group	Malaysia	713,698	0.25
Controladora Vuela Compania de Aviacion	Mexico	2,595,500	0.90
Air New Zealand	New Zealand	1,214,490	0.42
Cebu Air	Philippines	922,765	0.32
PAL Holdings	Philippines	1,403,523	0.49
Aeroflot Russian Airlines	Russia	2,217,748	0.77
Singapore Airlines	Singapore	11,008,923	3.81
Pegasus Hava Yollari	Turkey	865,175	0.30
Turk Hava Yollari	Turkey	2,159,177	0.75
Abu Dhabi Aviation	United Arab Emirates	512,244	0.18
Air Arabia	United Arab Emirates	1,715,250	0.59
Easyjet	United Kingdom	5,904,842	2.04
International Consolidated Airlines Group	United Kingdom	12,714,457	4,40
Wizz Air Holdings	Switzerland	5,630,318	1.95
Alaska Air Group	**United States**	**7,389,372**	**2.56**
American Airlines Group	United States	13,398,313	4.64
Delta Air Lines	United States	27,454,267	9.50
Southwest Airlines	**United States**	**31,243,971**	**10.81**
United Airlines Holdings	United States	16,534,807	5.72
Vietjet Aviation	Vietnam	2,709,372	0.94
Vietnam Airlines	Vietnam	1,610,257	0.56

Notes: Constituents and index weights in the Datastream World Airline Index as of July 14, 2021. Individual airlines considered in Section 4.4 in **bold font**.

Source: Refinitiv Datastream

A.3 Complete prior distributions

Table A.2: Prior distributions for model parameters in **A**, **B**, and **D**

Parameter	Economic meaning	Location	Scale	D.o.f.	Skewness	Sign
Priors on matrix of contemporaneous coefficients **A**						
		Student t distribution				
α_{qp}	Price elasticity of oil supply	0.1	0.2	3	—	$\alpha_{qp} > 0$
α_{yp}	Effect of p on economic activity	$-.05$	0.1	3	—	$\alpha_{yp} < 0$
β_{qy}	Income elasticity of oil demand	0.7	0.2	3	—	$\beta_{qy} > 0$
β_{qp}	Price elasticity of oil demand	-0.7	0.2	3	—	$\beta_{qp} < 0$
φ_1	Effect of q on oil inventories	0	0.5	3	—	none
φ_3	Effect of p on oil inventories	0	0.5	3	—	none
γ_{rq}	Effect of q on WAI excess returns	0	1	3	—	none
γ_{ry}	Effect of y on WAI excess returns	0	1	3	—	none
γ_{rp}	Effect of p on WAI excess returns	0	1	3	—	none
h_2	Effect of economic activity shock on y	0.8	0.2	3	—	none
		Beta distribution				
χ	Fraction of inventories observed	0.6	0.1	—	—	$0 \leq \chi \leq 1$
ρ	Importance of measurement error	0.25χ	0.12χ	—	—	$0 \leq \rho \leq 1$
		Asymmetric t-distribution				
h_1	Determinant of matrix **A**	0.6	1.6	3	2	none
Priors for structural variances $\mathbf{D}\vert\mathbf{A}$						
		Gamma distribution				
d_{ii}^{-1}	Reciprocal of variance/precision	$1/\left(\mathbf{a}_i'\mathbf{S}\mathbf{a}_i\right)$	$1/\left(\sqrt{2}\mathbf{a}_i'\mathbf{S}\mathbf{a}_i\right)$	—	—	$d_{ii} > 0$
Priors for lagged structural coefficients $\mathbf{B}\vert\mathbf{A},\mathbf{D}$						
		Normal distribution				
b_{13}	Lagged supply response to p	0.1	$\lambda_0^2 \cdot \left[\begin{matrix}\mathbf{v}_1 \otimes \mathbf{v}_2 \\ \lambda_3^2\end{matrix}\right]^{a}$	—	—	none
b_{33}	Lagged demand response to p	-0.1	$\lambda_0^2 \cdot \left[\begin{matrix}\mathbf{v}_1 \otimes \mathbf{v}_2 \\ \lambda_3^2\end{matrix}\right]^{a}$	—	—	none
b_{ij}	All other lagged responses	0	$\lambda_0^2 \cdot \left[\begin{matrix}\mathbf{v}_1 \otimes \mathbf{v}_2 \\ \lambda_3^2\end{matrix}\right]^{a}$	—	—	none

[a] $\mathbf{v}_1' = \left[1/\left(1^{2\lambda_1}\right), 1/\left(2^{2\lambda_1}\right), \ldots, 1/\left(m^{2\lambda_1}\right)\right]$, $\mathbf{v}_2' = \left(s_{11}^{-1}, s_{22}^{-1}, \ldots, s_{nn}^{-1}\right)'$, and $s_{ij} = T^{-1}\sum_{t=1}^{T} \hat{e}_{it}\hat{e}_{jt}$. Following the baseline specification of Baumeister and Hamilton (2019), we set $\lambda_0 = 0.5$, $\lambda_1 = 1$, and $\lambda_3 = 100$.

Note: For Student t and Normal distributions, the location parameter refers to the mode. For Beta and Gamma distributions, the location parameter refers to the mean and the scale parameter to the standard deviation. Adapted from Table 1 in Baumeister and Hamilton (2019)

A.4 Convergence diagnostics

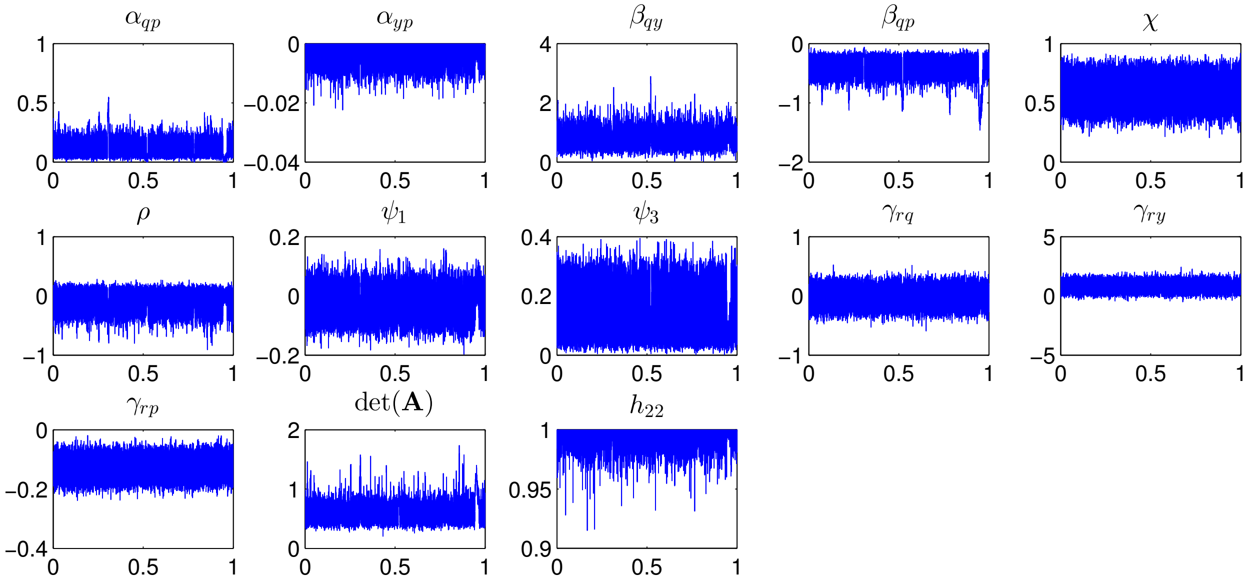

Figure A.2: Trace plots of posterior parameter draws

Note: Trace plots of parameter draws based on 1,000,000 MH iterations after 1,000,000 burn-in draws

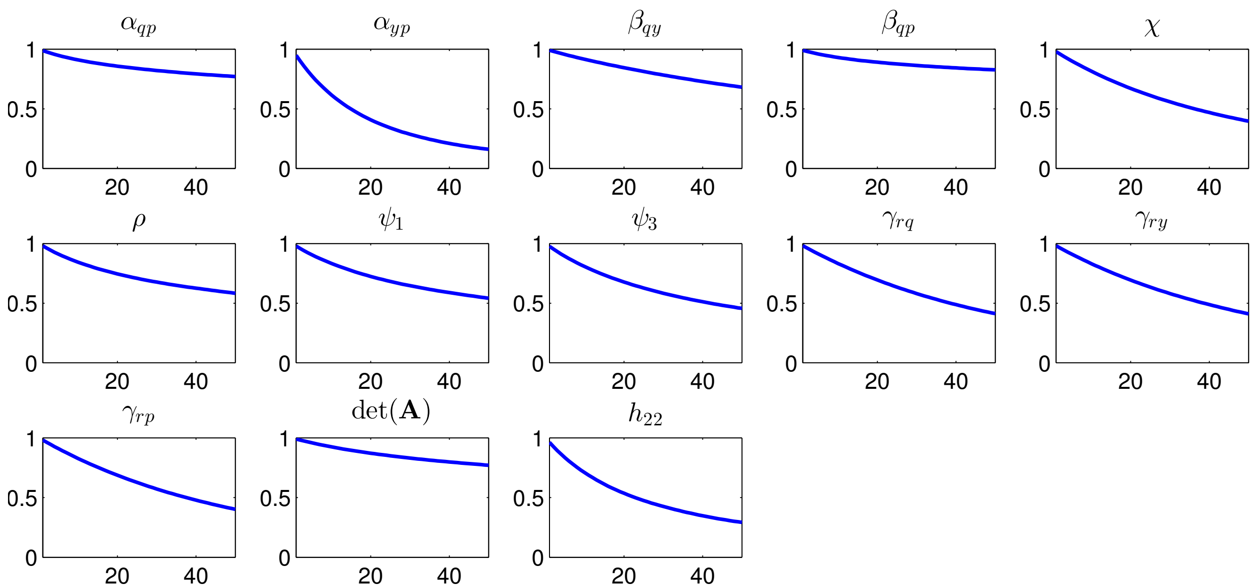

Figure A.3: Autocorrelation functions (ACF) of posterior parameter draws

Note: Sample ACF of parameter draws based on 1,000,000 MH iterations after 1,000,000 burn-in draws

A.5 Complete impulse response functions

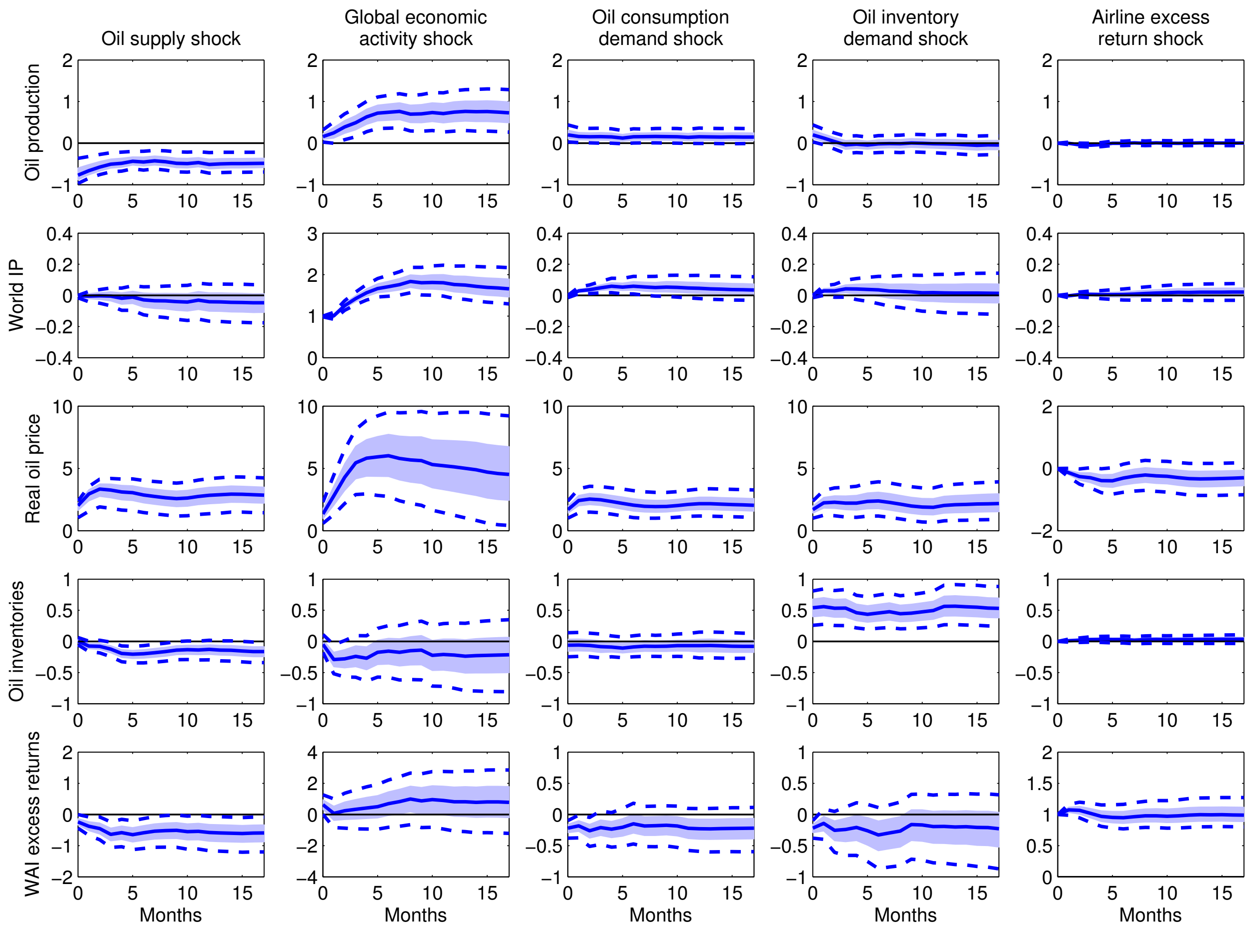

Figure A.4: Impulse response functions for the baseline 5-variable model in (3)

Note: Bayesian posterior medians (solid lines) with 68 percent (shaded areas) and 95 percent (broken lines) posterior credible sets based on 1,000,000 MH iterations after 1,000,000 burn-in draws

A.6 Complete historical decompositions

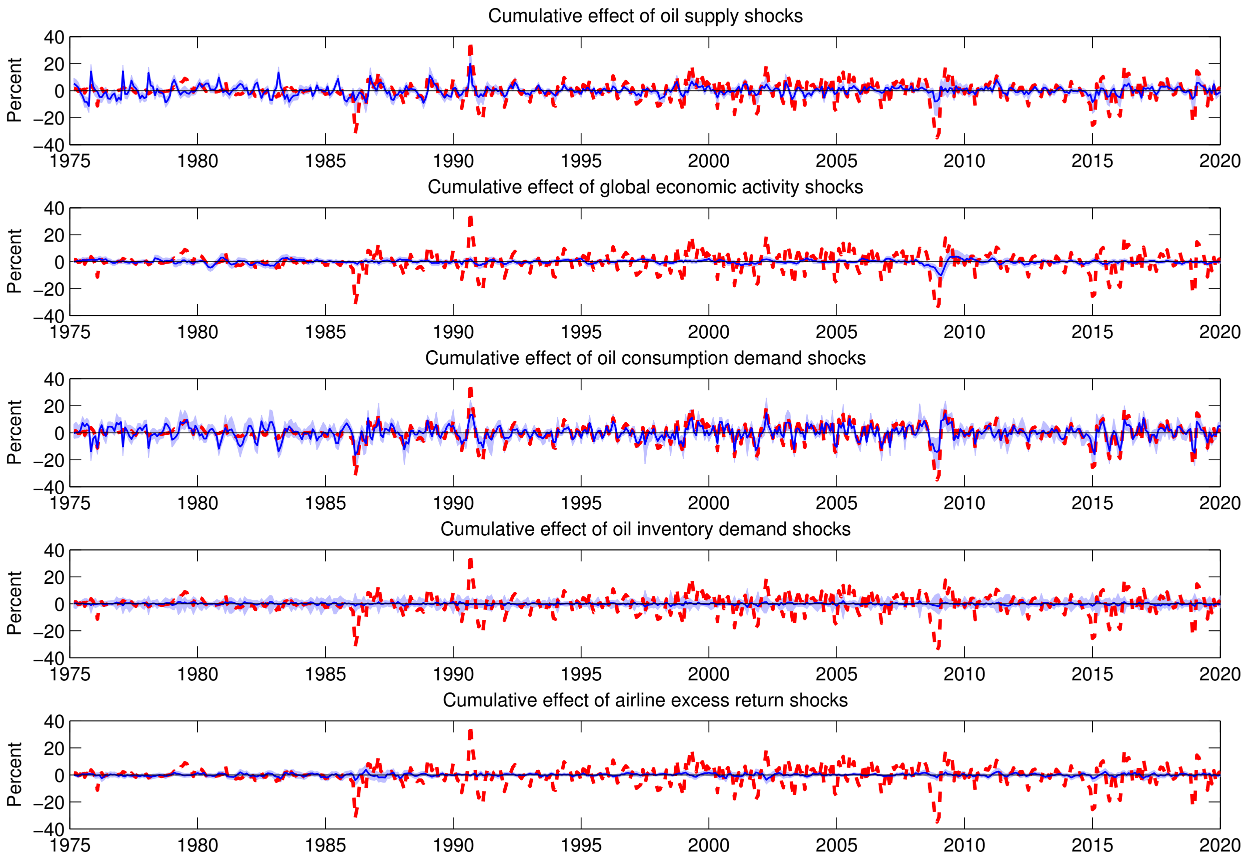

Figure A.5: Historical decomposition of real oil price growth for the baseline model in (3)

Note: Historical real oil price growth (broken lines) and median cumulative effects of structural shocks (solid lines) with 95 percent posterior credible sets (shaded areas) based on 250,000 MH iterations after 1,000,000 burn-in draws

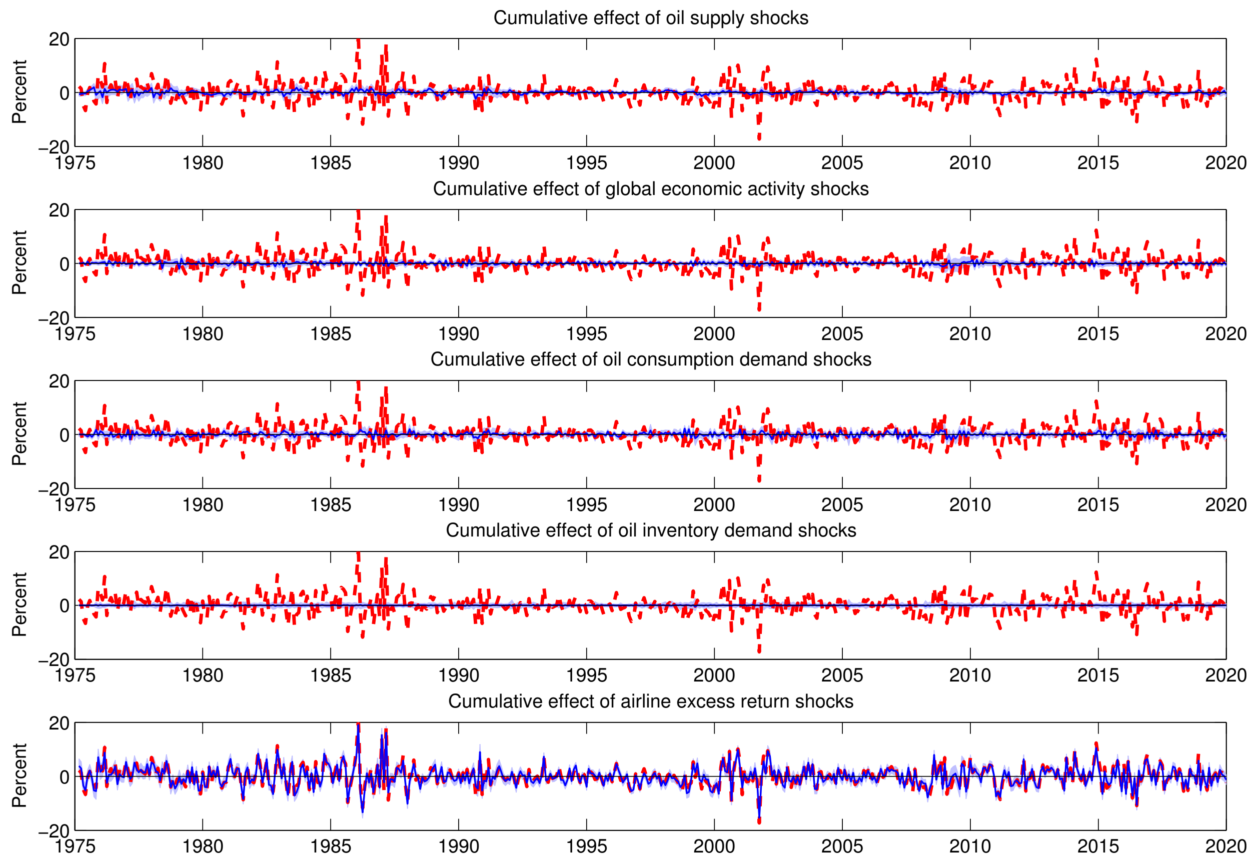

Figure A.6: Historical decomposition of WAI excess returns for the baseline model in (3)

Note: Historical WAI excess returns (broken lines) and median cumulative effects of structural shocks (solid lines) with 95 percent posterior credible sets (shaded areas) based on 250,000 MH iterations after 1,000,000 burn-in draws

A.7 Historical conditional comovement

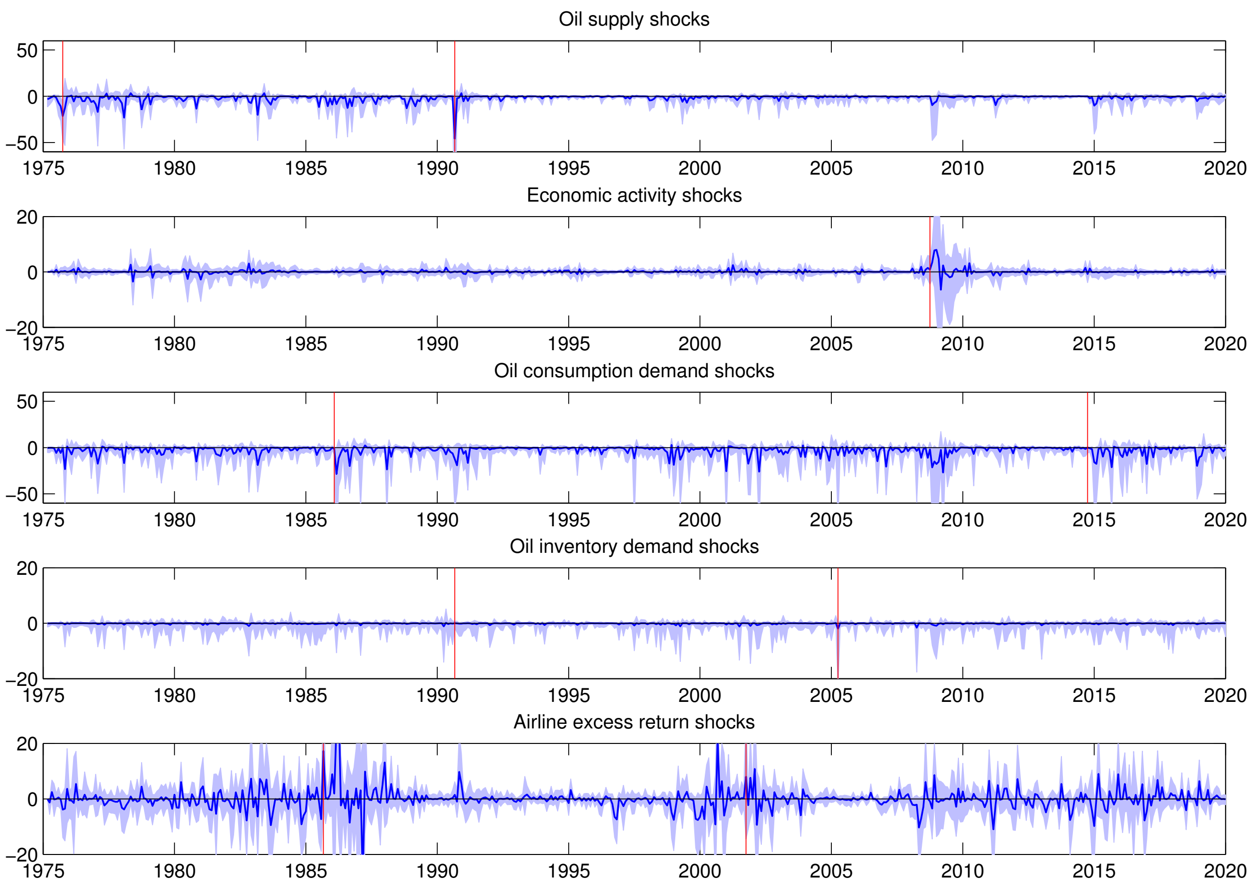

Figure A.7: Conditional comovement of cumulative effects on oil price growth and WAI excess returns

Notes: Pointwise median product of cumulative effects (solid lines) with 95 percent posterior credible sets (shaded areas) based on 250,000 MH iterations after 1,000,000 burn-in draws. Vertical lines indicate historical episodes discussed in the main text and shown in Figure 6.

A.8 Individual airline excess returns

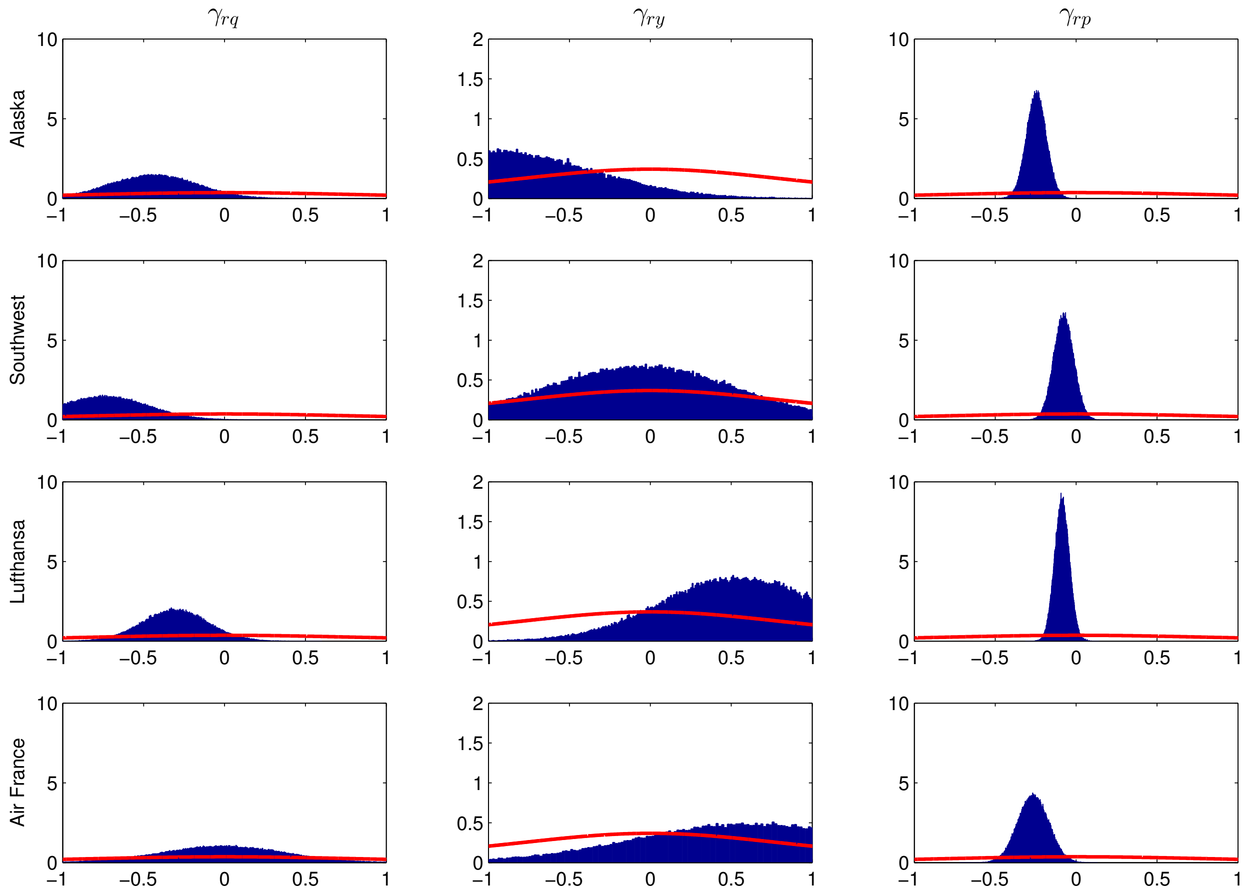

Figure A.8: Prior (solid red lines) and posterior (blue histograms) distributions of selected contemporaneous coefficients in **A** for the baseline 5-variable model in (3)

Note: Posterior distributions based on 1,000,000 MH iterations for each airline after 1,000,000 burn-in draws

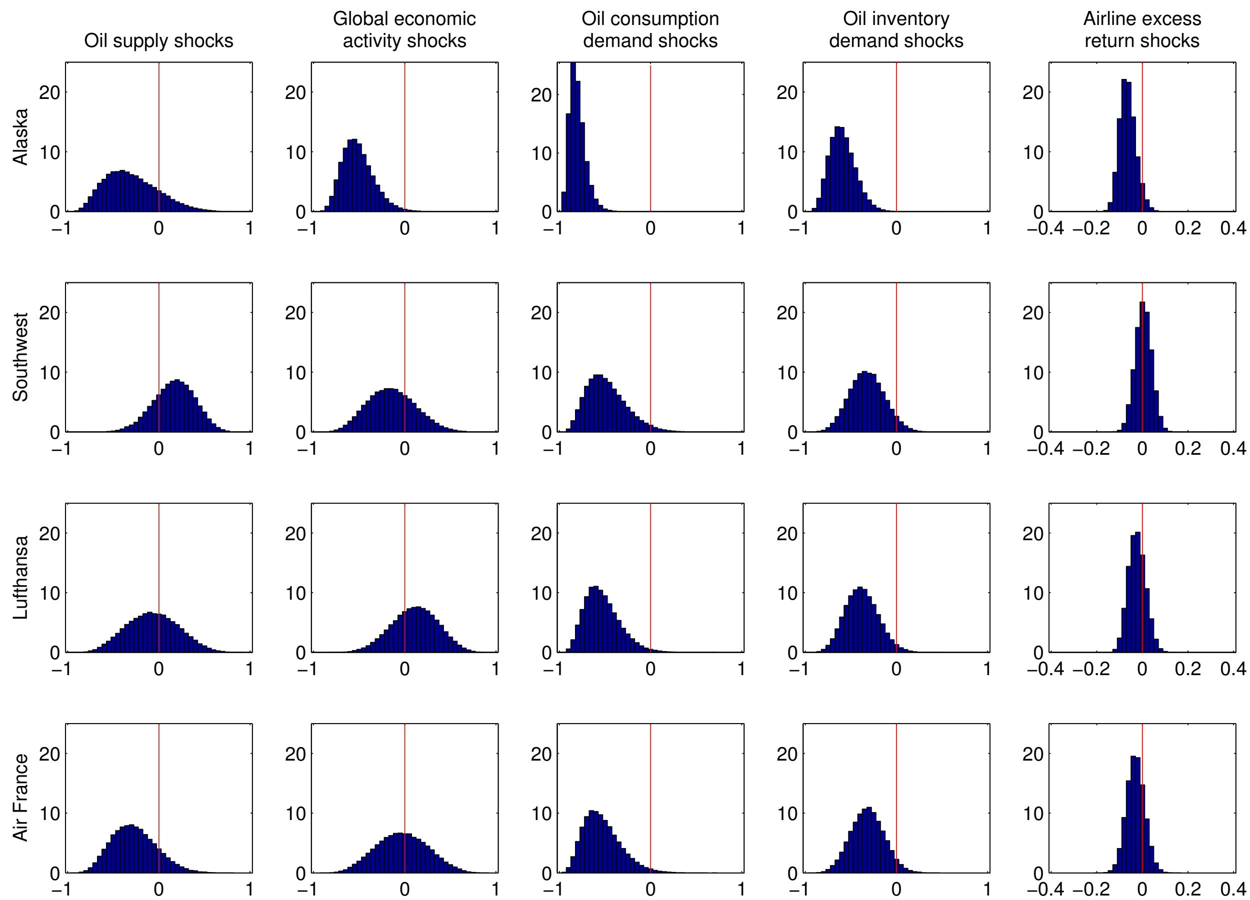

Figure A.9: Conditional correlations of cumulative effects on oil price growth and individual airlines excess returns for each structural shock

Note: Histograms of correlation coefficients between real oil price growth and excess returns on individual airline stocks conditional on each structural shock based on 100,000 MH iterations after 1,000,000 burn-in draws

A.9 World Hotel and Travel & Tourism Index

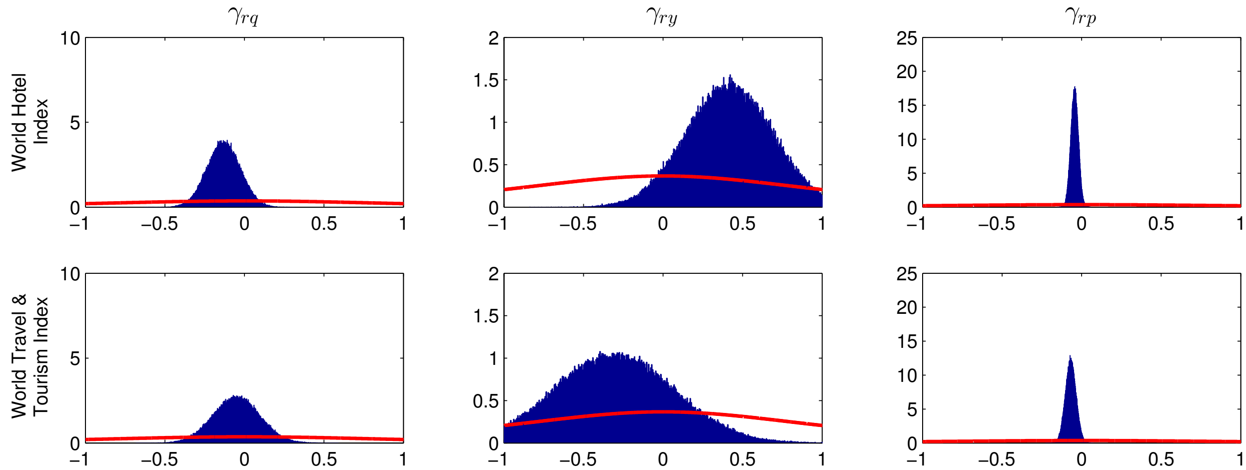

Figure A.10: Prior (solid red lines) and posterior (blue histograms) distributions of selected contemporaneous coefficients in $\mathbf{A}$ for the baseline 5-variable model in (3)

Note: Posterior distributions based on 1,000,000 MH iterations for each index after 1,000,000 burn-in draws

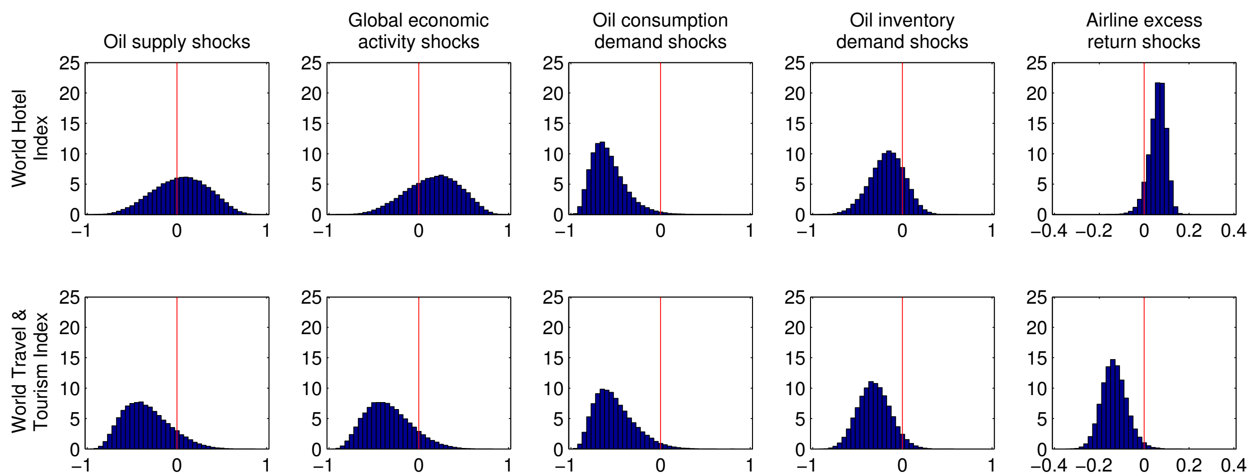

Figure A.11: Conditional correlations of cumulative effects on oil price growth with WHI and WTTI excess returns for each structural shock

Note: Histograms of correlation coefficients between real oil price growth and excess returns on DS World Hotel and World Travel & Tourism Index conditional on each structural shock based on 100,000 MH iterations after 1,000,000 burn-in draws