Industrial action in the air: impact of air traffic control strikes on flight efficiency

seo amsterdam economics

Industrial action in the air: impact of air traffic control strikes on flight efficiency

Gerben de Jong*[1, 2] and Rogier Lieshout[1]

[1]SEO Amsterdam Economics, Roeterstraat 29, 1018 WB Amsterdam, Netherlands

[2]School of Business and Economics, Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, Netherlands

February 28, 2020

Abstract

This paper analyses the causal impact of industrial actions at air navigation service providers on flight efficiency within the European air transport network. We match detailed flight trajectory data with information on the timing and location of all European air traffic control strikes between 2015 and 2017. Controlling for the endogenous timing of the strikes, we estimate the additional horizontal distance flown by affected flights. On average, flights that cross airspace sectors that are affected by strike action cover an additional 11 kilometres. The aggregate flight efficiency impact accumulates to 4.7 million kilometres flown during the 2015 - 2017 period. This impact is substantial as compared to another common type of airspace disruption, technical failures. Given that the efficiency impacts are concentrated in countries where overflights are not guaranteed, EU-wide minimum service requirements for overflights appears to be an effective policy to preserve efficiency of the air transport system in the face of industrial action.

Keywords: flight efficiency, airspace disruptions, industrial action, air traffic control strikes, air navigation service providers

Acknowledgments: The research reported in this paper is carried out with financial support from Airlines for Europe. We are grateful to Eurocontrol for providing data. We also thank Arnout Jongeling, Valentijn van Spijker and Tom Verboon for research assistance and Carl Koopmans as well as participants at the ATRS 2019 World Conference for valuable comments. The views expressed in this paper are ours alone.

* *E-mail address corresponding author:* g.dejong@seo.nl (G. de Jong)

1 Introduction

Industrial action at air navigation service providers (ANSPs) gain a lot of attention within the popular press.[1] Strikes by European air traffic controllers (ATCs) disrupted the functioning of Europe's airspace on average once in every twelve days over the 2004 − 2016 period (Horton and Congdon, 2017). Such disruptions lead to the temporary closure or limitation of capacity in airspace sectors. This negatively impacts passengers and airlines through flight delays and cancellations, causing longer travel times, disrupted travel plans, cost increases and extended working time for personnel. Besides these visible impacts, industrial actions may also lead to less visible impacts such as the rerouting of aircraft in order to circumvent the affected airspace sectors.

Recognizing the disruptive impact of industrial actions at ANSPs on the functioning of the air transport network, the European Commission issued a staff working document aimed at exploring the impact of ATC strikes and identifying best practices for minimizing disruption while maintaining employees' fundamental right to strike (European Commission, 2017).[2] Although the economic impacts of ATC strikes in terms of delays and flight cancellations have been documented by industry and governmental reports (PWC, 2016; Horton and Congdon, 2017), there is very little evidence on its impact on flight efficiency. As flight distance is one of the crucial factors determining fuel consumption and CO_2-emissions (e.g., Swan and Adler, 2006; Brueckner and Abreu, 2017), inefficient flight paths not only affect passengers and airlines but also the environment.[3]

To the best of our knowledge, Horton and Congdon (2017) provide the only calculation to date of the flight efficiency impact of industrial actions at ANSPs, suggesting that the additional flight distance incurred by European ATC strikes in 2014 and 2015 amounts to over 2 million kilometres. Their back-of-the-envelope calculation is based on aggregate distance flown in the European air transport network and hence provides a rather general picture of the flight efficiency impact. More fundamentally, the calculation does not control for confounding factors that influence flight efficiency irrespective of the occurrence of strike action. As actions are unlikely to occur randomly over time confounding factors may be correlated to the strikes.[4] The estimation of the flight efficiency impact provided so far can therefore not be interpreted as causal.

[1] See, among others, BBC (2013), Travel Weekly (2015) and The Times (2019).

[2] This initiative was part of a broader set of measures to reinforce the global competitiveness of the European aviation sector in support of the Aviation Strategy for Europe initiative of 2015.

[3] Due to flight cancellations, the net effect of industrial actions at ANSPs on the environment are likely positive.

[4] For instance, actions may be planned during peak periods to maximize strike effectiveness or, on the contrary, may mainly take place in off-peak periods due to legislation that restricts striking during peak periods in some countries.

The current paper isolates the causal effect of industrial action at ANSPs on flight efficiency by matching detailed information on the timing and location of European ATC strikes in the period between 2015 and 2017 with microdata on the universe of flights within Europe.[5] Specifically, we estimate the additional horizontal flight distance incurred by flights on routes that cross the affected airspace sectors. To control for the endogenous timing of strikes, we combine a difference-in-difference model with a matching procedure. By this approach the *difference* in the horizontal flight distance of the group of affected flights on the day of the disruption and the week before, is compared to the same *difference* for a group of unaffected flights with similar characteristics.

We expand the findings from this baseline model into two directions. First, we investigate to what extend the impact of industrial actions varies across countries. Heterogeneous impacts between countries may arise due to differences in country size and geographic location, but potentially also due to differences in national legislation with respect to industrial actions. The latter differences may provide useful clues for identifying policies that mitigate the impact of industrial actions. Second, we analyse the efficiency impact of another common type of airspace disruption: technical failures. This sheds light on the relative impact of industrial actions. If the impact of industrial actions is large as compared to the impact of technical failures, this provides evidence that the current policy attention for reducing the impact of industrial actions is warranted.

Our main findings are as follows. Industrial actions at ANSPs increase the horizontal flight distance of affected flights by 11 kilometres on average. This average effect masks substantial heterogeneity: some industrial actions have no statistically significant efficiency impact while others increase average flight distances by up to 75 kilometres per affected flight. Industrial actions also differ substantially in terms of the number of flights affected - ranging from 300 up to 8,000 ongoing flights per day of the industrial action. By combining the number of affected flights with our estimates of the efficiency impact, we calculate that the aggregate additional flight distance flown due to industrial actions is equal to 4.7 million kilometres flown within Europe between 2015 - 2017.

Compared with the flight efficiency impact of technical failures, the impact of industrial action is substantial. At the same time, its efficiency impacts are concentrated in countries where due to national legislation the servicing of overflights is not guaranteed. Hence, in terms of policy recommendations, an EU-wide guarantee of overflights during industrial action may almost fully mitigate the flight inefficiencies identified in this paper.

[5]For the purpose of our analysis, we define Europe to include all countries that were part of the European Economic Area (EEA) during the period of analysis (2005-2017) plus Switzerland.

This paper contributes to an emerging literature on the efficiency of flight trajectories. Various studies estimated the impact of Europe's fragmented airspace on flight trajectory optimality. For instance, Button and Neiva (2013) quantified the potential efficiency improvements of functional airspace blocks. Reynolds (2014) developed various various flight efficiency metrics to quantify how far aircraft deviate from their optimal trajectory in different flight phases. Ryerson et al. (2014) analysed the potential fuel savings from air traffic management improvements that allow flights to better adhere to their planned trajectories. Efthymiou and Papatheodorou (2018) use a Delphi approach to analyse policy issues related to operational efficiency and environmental aspects of the Single European Sky initiative. We extend this line of research by considering the flight efficiency implications of airspace disruptions.

The remainder of this paper is organised as follows. Section 2 describes the background on industrial action at European ANSPs. Section 3 presents the data and the econometric approach. Section 4 discusses the results. Section 5 concludes.

2 Background

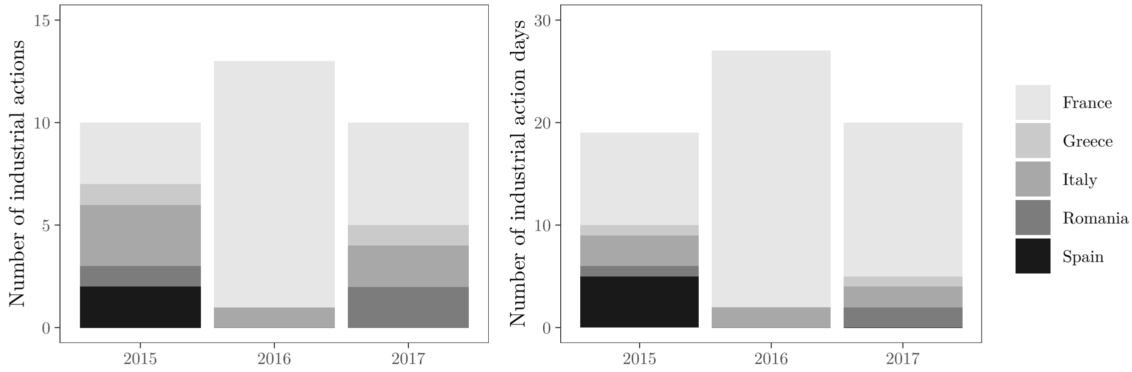
During the 2015 - 2017 period, European ATCs went on strike 33 times covering 66 days in total.[6] The strike actions were typically the outcome of bargaining between governments and unions on wage and employment levels, but may also be out of solidarity with national labour disputes.[7] As Figure 1 shows, most of the industrial actions took place at the French (60 percent) followed by the Italian ANSPs (18 percent). The actions in France were for the most part solidarity strikes, while the majority of the actions in Italy had to do with the privatisation of the national ANSP. Where the actions in countries such as Italy and Greece are generally limited to a few hours, the French usually last at least the entire day (midnight to midnight) and often span multiple days. In terms of days with industrial actions, France is therefore responsible for an even larger share (74 percent) than in terms of the number of actions.

Government and industry reports assessed the economic impacts of industrial actions at European ANSPs (PWC, 2016; Horton and Congdon, 2017). PWC (2016) found that these actions had reduced EU gross domestic product and employment by 10.4 billion euro and 143,000 jobs respectively over the 2010 - 2015 period. The majority of these impacts consist of: reduced tourism spending as passengers cancel (part of) their holiday (59 percent), reduced productivity as passengers have to

[6] Appendix A contains a detailed overview of all strikes at European ANSPs between 2015 and 2017.

[7] See Blondiau et al. (2018) for a formal union-bargaining model in the context of European ANSPs.

Figure 1: Number and days of industrial actions at European ANSPs, 2015 - 2017



Note(s): Based on Eurocontrol Network Operation Reports (Eurocontrol, 2016, 2017, 2018)

spend more time travelling (35 percent) and reduced airline revenues due to cancellations (6 percent). Horton and Congdon (2017) estimated that a single industrial action may cost airlines over 15 million euro. This includes the costs of delays, additional distance flown and the costs of flight cancellations.

To illustrate how an industrial action affects airspace capacity and, in turn, individual flight trajectories, Figure 2 shows the consequences of an industrial action at the French ANSP on the 22nd of March 2018. On this day, 28,252 flights operated in European airspace of which 5,405 operated in or near French airspace. During the industrial action, airspace regulations were issued for most parts of French airspace.[8] These regulations reduced available airspace capacity. The majority of these regulations limited capacity by less than 50 percent and only a few regulations limit capacity to zero. Nonetheless, as shown by the maps, numerous flights between the Southwest and Northeast of Europe were rerouted westbound and eastbound of French airspace.

3 Data and approach

We are interested in isolating the causal effect of industrial actions on flight efficiency. The main intuition behind our analysis is that we compare the horizontal flight distance of affected flights on the day of the industrial action with the horizontal flight distance of these flights on the day exactly one week before the industrial action (the 'reference' day). We use a matched group of unaffected flights to control for time variations in flight distance that are unrelated to the strike. As such,

[8] A regulation is a limit on the rate of aircraft that may enter a volume of airspace. Each regulation is assigned a cause (e.g., industrial action), which is what we use to identify which airspace sectors were affected by each industrial action.

Figure 2: Flights circumventing airspace sectors affected by industrial action

(a) Westbound (b) Eastbound

Note(s): Based on Eurocontrol flight traffic data (Eurocontrol, 2019)

our estimates of the additional kilometres flown on the day of the industrial action can be causally ascribed to the industrial action.

3.1 Data

The analysis is primarily based on flight traffic data obtained from Eurocontrol through their Demand Data Repository service (Eurocontrol, 2019). This data contains detailed information on all flights passing through Europe's airspace, including the call sign, origin and destination, flight date, departure and arrival time, operating airline, aircraft type, flight trajectory and distance. Because flight trajectories are only recorded within European airspace sectors, our analysis focusses on intra-European flights (i.e., flights within the EEA plus Switzerland). We drop flights with unknown airline designator codes and with designator codes known to be of Air Forces and other military or rescue organizations. We also exclude flights for which the origin airport is equal to the destination airport, most of which have (close to) zero flight distance.

Based on Eurocontrol's Network Operation Reports (Eurocontrol, 2016, 2017, 2018), we list all industrial actions that took place at European ANSPs between 2015 and 2017. We identify which airspace sectors were affected by each of the industrial actions using information on regulations within European airspace sectors, which is provided by Eurocontrol's Demand Data Repository service.[9]

[9]We drop four industrial action days because they only affected airports (i.e., no airspace sectors were regulated) and one industrial action day for which there was no suitable reference day. For the latter, potential reference days were also disrupted by either industrial actions or technical failures.

We match this information to the flight traffic data and construct a separate dataset for each industrial action day between 2015 and 2017. These datasets contain all intra-European flights on the day of that specific industrial action and the day exactly one week earlier (the 'reference' day).[10] All routes that crossed the affected airspace sectors on the industrial action day *or* the reference day are flagged as affected routes, while all flights operated on affected routes on the industrial action day are flagged as affected flights.[11] By this approach, we also capture flights that completely circumvented the affected sectors during the industrial action.

3.2 Descriptive statistics

Table 1 provides descriptives on all European routes and affected routes subdivided by reference and industrial action days. There are approximately 19,000 flights covering just over 8,000 routes per day in our data. The average industrial actions affects about 4,000 flights and 1,800 routes. The number of European routes and flights are slightly lower on industrial action days as compared with reference days. This decrease is much more substantial on affected routes, reflecting that flights on these routes are cancelled during the action. After flight cancellations, the average industrial action day affects 3,818 *ongoing* flights on 1,805 routes. There are however substantial differences between industrial actions. The least severe industrial action affected only 307 flights on 177 routes, while the most severe industrial action affected almost 8,000 flights and over 3,500 routes on a single day.

The average flight distance of European flights is 940 kilometres on reference days and 944 kilometres on days with industrial actions. Affected routes are not only longer on average, the difference in flight distance between days with industrial actions (1,388 kilometres) and reference days (1,416 kilometres) is also larger. This is in line with flight inefficiencies caused by industrial actions, although the difference cannot be interpreted as the causal effect due to the endogenous timing of actions.

[10] In a few cases the day one week before the industrial action was also affected by an industrial action. In such cases we use the day one week after the industrial action as the reference day. We apply a similar approach for industrial actions that occurred at the start of the summer and winter seasons (first week of April and November), as flight schedules differ significantly between summer and winter seasons and therefore are not comparable.

[11] Based on the data available to us we cannot determine which flights were (supposed to be) in the affected airspace sectors at the time that the industrial action took place. We therefore cannot take into account that strikes do not always last a full day. We note however that due to knock-on effects even flights departing just after the industrial action could be flying less efficient flight trajectories due to congestion caused by delayed flights. Moreover, our aggregate calculations are not affected by this shortcoming, since the higher number of affected flights is corrected by a lower average efficiency impact per flight.

Table 1: Descriptive statistics

	Reference days			Industrial action days	
	Mean	Std dev		Mean	Std dev
All intra-EEA routes:					
Number of flights	19310	2344		19169	2325
Number of routes	8021	1107		8013	1089
Average route frequency	2.42	0.14		2.40	0.13
Average flight distance	940.45	81.18		943.78	81.13
Affected routes:					
Number of flights	4004	2289		3818	2167
Number of routes	1866	1054		1805	999
Average route frequency	2.12	0.18		2.09	0.20
Average flight distance	1388.18	247.63		1415.78	247.40
Industrial actions			33		
Industrial action days			61		

3.3 Econometric framework

Two main econometric issues need to be addressed to isolate the causal impact of industrial actions. First, due to flight cancellations, the group of flights on affected routes on the day of the industrial action may be different from the flights on affected routes on the reference day. If flight cancellations include predominantly flights over longer distances, then the average flight distance on the day of the disruption will be decreased. Note that this does not mean that the flight distance of individual flights has decreased; the decrease is only due to a *change in the composition* of flights. To control for this composition effect, we only maintain those flights that were operated both on the day of the industrial action and reference day by identifying matches in the combination of call sign, origin and destination of flights.

Secondly, industrial actions are not planned in a random manner and therefore unobserved factors that may also affect flight efficiency are likely to be correlated with the occurrence of industrial actions. For example, industrial actions may be planned during peak periods in which trajectories are already less efficient due to the amount of traffic in the skies. To resolve this issue, we employ a difference-in-difference model that compares the *difference* in the flight distance of affected flights on the day of the industrial action and the reference day, to the same *difference* in a control group of unaffected flights.[12] This approach provides the causal effect of the industrial action under the assumption that the time trend in flight distance is similar in the treatment and control groups.

[12] See, e.g., Angrist and Pischke (2009); Imbens and Wooldridge (2009) for an extensive treatment of difference-in-difference models.

To select a suitable control group, we implement a statistical matching procedure called nearest neighbour matching (Rubin, 1979).[13] This procedure matches each affected route to an unaffected route with approximately the same route length and number of daily flights flown on the route based on reference day flight data. All flights on the matched routes comprise the control group against which the affected flights are compared.

Formally, let y_{ij} be the horizontal flight distance of a flight on route i associated with industrial action j (i.e., operated on the day of industrial action *or* its reference day). Let $T = 0, 1$ be an indicator for affected routes, where 1 indicates routes that are affected by the industrial action, and 0 indicates routes that are not affected by the industrial action. Let $t = 0, 1$ be an indicator for time periods, where 1 indicates the day of the industrial action, and 0 indicates the reference day. For each individual industrial action, we estimate the following specification:

$$y_{ij} = \alpha_{ij} + \beta_j t_{ij} + \gamma_j (T_{ij} \cdot t_{ij}) + \epsilon_{ij} \tag{1}$$

where α_{ij} is a route fixed effect that accounts for average differences between routes; β_j captures the common time trend for affected and control flights; γ_j provides an estimate of the additional flight distance incurred by affected flights due to the industrial action; and ϵ_{ij} is a random error term.

Note that all coefficients are j-specific, which means that we estimate the model for each industrial action separately. To combine the coefficient estimates into an average flight efficiency impact over all industrial actions, we use the *inverse variance weighted average* method:

$$\overline{\gamma} = \frac{\sum w_j \gamma_j}{\sum w_j} \tag{2}$$

with weights w_j set equal to the inverse variance of each estimate $[SE(\gamma_j)^2]^{-1}$. The standard error of this average flight efficiency impact is $SE(\overline{\gamma}) = \sqrt{(\sum w_j)^{-1}}$. Note that we can also obtain the least and most severe flight efficiency impacts by searching for the minimum and maximum over γ_j.

This specification allows for heterogeneous effects across industrial actions. Specifically, each industrial action can have a different common time trend for affected and control flights and, importantly, a different flight efficiency impact. This also enables us to assess how the impact of industrial actions varies across countries, by employing the inverse variance weighting method of Eq. (2) on the subset of industrial actions in each country.

[13] To implement this matching procedure, we estimate the propensity score for each route, i.e. the (logit) probability of being affected by the industrial action given the route length and daily route frequency (Rosenbaum and Rubin, 1983). Matching is than executed by selecting (without replacement) the closest match for each affected route in terms of this propensity score. We test the robustness of our results to alternative matching procedures in section 4.2.

Table 2: Baseline model estimation results

	Baseline model		
	Coef	Std err	p-val
Average ($\overline{\gamma}$)	10.824	0.248	0.000
Minimum ($\min \gamma_j$)	-3.132	4.161	0.452
Maximum ($\max \gamma_j$)	75.438	4.243	0.000
Industrial action days		61	
Flight observations		798,536	

Note(s): Robust standard errors, clustered by routes.

4 Results

4.1 Industrial action results

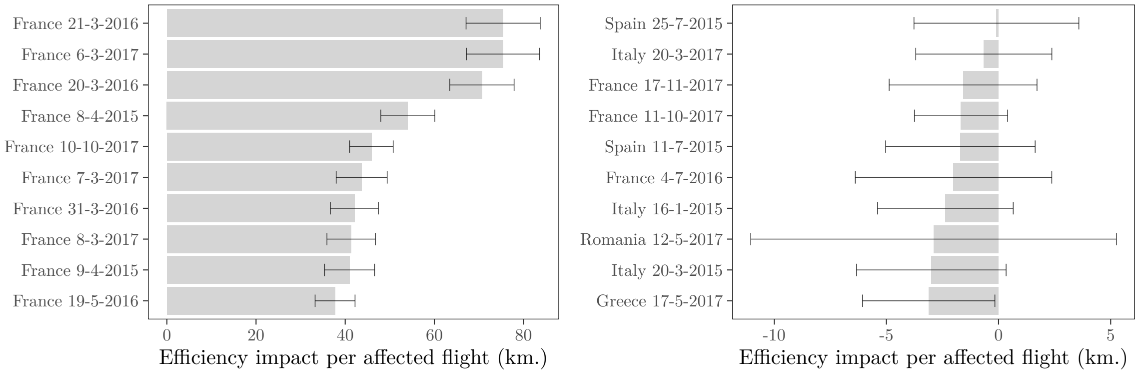
Table 2 provides the estimates of the flight efficiency impacts of industrial actions. The columns contain respectively the coefficients, standard errors and p-values obtained from the baseline model of Eq. (1). The average flight efficiency coefficient is estimated using the inverse variance weighting method of Eq. (2). The minimum and maximum coefficients correspond to the estimates of the industrial action with, respectively, the lowest and highest flight efficiency impact. Standard errors are robust and clustered on the route level.[14] The estimates are obtained by using 798,536 flights associated with the 61 independent industrial action days during our analysis period.[15]

In the baseline model the average flight efficiency impact over all industrial action days is equal to 10.824. This means that flights affected by industrial actions at European ANSPs on average cover an additional 11 kilometres. This average effect is statistically significant at conventional significance level (p-value ≤ 0.01). The flight efficiency impact varies widely across the individual industrial actions, as can be seen from the minimum and maximum impact and from Figure 3 which shows the industrial actions with the most and least severe flight efficiency impact. The most severe flight efficiency impact equals over 75 kilometres of additional flight distance per affected flight. The least severe industrial actions have negative signs, which suggests that these industrial action led to more efficient flight trajectories. Such effects might be explained by the fact that flight cancellations reduce congestion in affected airspace sectors which allows the remaining flights to follow more efficient trajectories. In all cases with negative signs, however, the efficiency gains are small and not

[14]This allows errors to be correlated within routes, but not across routes. Not clustering on the route level may lead to misleadingly small standard errors and increases the probability of falsely rejecting the null hypothesis of no flight efficiency impact (Cameron and Miller, 2015).

[15]The estimation results for all individual industrial actions are shown in Appendix B.

Figure 3: Most and least severe industrial actions in terms of flight efficiency impact



Note(s): Length of bars equals estimated flight efficiency impact; error bars show the 95% confidence intervals.

Table 3: Average flight efficiency impact by country

	Number of industrial	Mean number of	Average flight efficiency impact		
Country	action days	affected flights per day	Coef	Std err	p-val
France	45	4526	14.671	0.290	0.000
Greece	2	3414	0.120	0.958	0.900
Italy	6	2332	0.272	0.669	0.684
Romania	3	606	4.681	1.940	0.016
Spain	5	1320	0.214	1.100	0.845

statistically significant.

Table 3 depicts the results by country in which the industrial action occurred. The average flight efficiency impact and the number of affected flights are largest for France. This likely owes to the country's size and its central location within the European airspace. The average flight efficiency impact in Romania is also positive and statistically significant. Industrial actions in the other countries (Greece, Italy and Spain) do not have a statistically significant impact on flight efficiency. This pattern is not surprising given that Greece, Italy and Spain guarantee all overflights during industrial actions (Horton and Congdon, 2017).[16] Such policies are not installed in France (guarantee of 50 per cent of overflights) and Romania (guarantee of 33 per cent of overflights), causing airlines to take detours in the face of industrial actions in those countries.

[16]Such requirements can be installed by law or through agreement with unions (Horton and Congdon, 2017).

4.2 Sensitivity analyses

To test the robustness of our results, we subject the baseline model estimates to a range of sensitivity analyses. Appendix C provides the results of these sensitivity analyses.

First, we investigate whether the flight efficiency impacts hold if we restrict the analysis to major airlines. For this purpose we rank all airlines by the aggregate number of flights they operate on the reference day, and restrict our analysis on the top-100 airlines for each industrial action.[17] As shown in column (1) of Table C.1 this restriction does not have a significant effect on our flight efficiency impact. This assures that the flight efficiency impact is not solely driven by smaller airlines.

Second, we check whether our estimates are robust to the exclusion of outliers. To this end we censor our data to exclude all flights that belong to the top and bottom 5 percent in terms of flight distance. As can be seen in column (2) of Table C.1 this somewhat reduces the flight efficiency impact. For instance, the average impact becomes 9.211 additional kilometres per affected flight. This lower estimate is in line with excluding flights that take long detours. Nevertheless, even without considering such outliers, the flight efficiency impact of industrial actions remains substantial.

Third, we isolate the impact on overflights, by excluding all flights that originate or depart in the country of the industrial action. In contrast to local flights, overflights can be rerouted around the affected airspace sectors. Although overflights may therefore be less likely to be cancelled, column (3) of Table C.1 indicates that the flight inefficiency impact for overflight is substantially larger.

Fourth, we conduct a quasi placebo test to rule out that our estimation method picks up inefficiencies due to other factors than industrial actions. For each industrial action we select a 'placebo' day, which is equal to the day exactly one week before the reference day.[18] We act as if the industrial action occurred on that day instead of on the actual industrial action day, and estimate the placebo flight efficiency impact using our modelling approach. As shown in Table C.2, the average flight efficiency impact over all placebo actions is almost exactly equal to zero.[19] This lends strong support to the claim that our estimation strategy picks up the additional distance flown due to industrial actions and not some general variation in flight distance.

[17] The top-100 airlines operate between 85 and 90 percent of all European flights.

[18] In the cases where the reference day was equal to the day one week *after* the industrial action, we set the placebo day equal to the day one week after the reference day. Moreover, if the placebo day was affected by another industrial action or technical failure, we use the day two weeks before the reference day.

[19] As shown by the maximum and minimum estimates, the placebo effect is significantly different from zero for some individual industrial actions. However, in all such cases the absolute magnitude of the placebo effect is small as compared to the actual treatment effect.

Table 4: Estimation results for technical failures model

	Baseline model		
	Coef	Std err	p-val
Average ($\overline{\gamma}$)	2.220	0.308	0.000
Minimum ($\min \gamma_j$)	-7.733	2.687	0.004
Maximum ($\max \gamma_j$)	58.308	18.177	0.002
Technical failure days		72	
Flight observations		381,300	

Note(s): Robust standard errors, clustered by routes.

Finally, we test the sensitivity of our results to various implementation of the matching procedure. We focus on alternative matching procedures that potentially increase the quality of the matches at the costs of reducing the number of observations (see, e.g., Caliendo and Kopeinig, 2008).[20] As shown in Table C.3, restricting the maximum propensity score distance between matched pairs leads to slightly lower estimates, whereas applying matching with replacement and optimal matching leads to estimates that are very similar to our baseline.[21]

4.3 Comparison with technical failures

In this section we use our model to estimate the flight efficiency impact of airspace disruptions caused by technical failures. The purpose of this analysis is to put the flight efficiency impact of industrial actions into perspective by comparing it with another common type of airspace disruption. Over the 2015 - 2017 period, 64 technical failures occurred in European airspace.[22] Most of these are related to failures of radar and communication systems. Contrary to industrial actions, technical failures occur unexpectedly. On the other hand the impact of technical failures is typically more localised and hence affect smaller number of airspace sectors.

Table 4 provides the estimation results of the flight efficiency impacts of technical failures. The average flight efficiency impact over all technical failures equals approximately 2.2 additional kilometres per affected flight (p-value ≤ 0.01), which is considerable below the average impact of industrial actions. The most severe technical failure, in terms of flight efficiency impact, caused almost 60

[20]Given the large number of flight observations in our data, matching procedures that increase the number of observations at the potential cost of decreasing matching quality are not useful here.

[21]We prefer our baseline estimates over the method that imposes a maximum distance between matched pairs, since this method requires setting a certain arbitrary tolerance distance (Smith and Todd, 2005).

[22]Of these 64 technical failures we use 55 in our analysis; we drop technical failures that did not affect airspace sectors and two cases where the technical failure lasted for over ten days. As some technical failures last longer than one day, this amounts to 72 days on which a technical failure occurred.

additional kilometres per affected flight. Nevertheless, this is still below the impact of the most severe industrial action. Overall, this suggests that technical failures have weaker flight efficiency impacts than industrial actions.

4.4 Aggregate additional flight distance due to industrial actions

To complete our analysis we estimate the aggregate additional flight distance flown due to industrial actions over the 2015 - 2017 period. Specifically, we combine the flight efficiency impact γ_j with the number of affected flights n_j for each industrial action j as follows $\sum_j \gamma_j n_j$. As we only observe European flights these calculations serve as the lower bound of the total additional flight kilometres caused by industrial actions.

Table 5 presents four different aggregate calculations. The first row represents the total impact of all industrial actions, estimated by the number of flights operated in affected airspace sectors on each of the 61 industrial action days multiplied with the baseline model estimate of the flight efficiency impact of that industrial action. The aggregate impact sums up to $4,729,076$ additional flight kilometres. Based on the average flight distance of about 950 kilometres for European flights (see Table 1), this is approximately equal to 5,000 intra-European flights.

It may be preferable to only consider the industrial actions that yield statistically significant efficiency impacts, as is done in the second row. While this considerably decreases the number of industrial action days and affected flights in the calculation, this does not substantially alter the aggregate impact figure. This suggests that industrial actions with insignificant flight efficiency impacts more or less cancel each other out.

The third row present the aggregate additional flight distance due to industrial actions in countries where overflights are not guaranteed. In line with our finding that the flight inefficiency impact of strikes outside of these countries are not statistically significant, this aggregate impact is almost equals the aggregate impact that considers all industrial actions. This shows that the additional flight kilometres are almost completely concentrated at strikes in countries that do not guarantee the serving of overflights during industrial actions.

Finally, as a means of comparison, we estimate the aggregate additional kilometres flown due to technical failures in the same period. Although technical failure-related airspace disruptions are more common, the total number of affected flights is considerably lower. Combined with the weaker flight efficiency impact this leads to technical failures having a considerably weaker impact on the efficient functioning of the European air transport network as compared to industrial actions.

Table 5: Additional flight distance caused by industrial action, 2015 - 2017

	Total number of disruptions	Total number of affected flights	Aggregate additional flight distance
Industial actions:			
All industrial actions	61	232,917	4,729,426
Industrial actions with significant flight efficiency impact	42	191,647	4,728,625
Industrial actions in countries where where overflights are gauranteed	48	205,501	4,721,488
Technical failures:			
All technical failures	72	106,277	321,960

5 Conclusion

This paper provides the first comprehensive appraisal of the flight efficiency impact of industrial actions at ANSPs. The analysis measures the additional flight distance for European flights affected by industrial actions at European ANSPs over the 2015 - 2017 period, while taking into account the endogenous timing of industrial actions. Furthermore, a comparison is made between the flight efficiency impact of industrial actions and the efficiency impact of airspace disruption due to technical failures.

On average, each flight affected by an industrial actions covers an additional 11 kilometres. This accumulates to 4.7 million additional kilometres flown within Europe during the 2015 – 2017 period. The impacts differ significantly among industrial actions. Impacts are largest for industrial actions occurring in France followed by Romania. For countries that do guarantee all overflights, such as Greece, Italy and Spain the impacts on flight efficiency are not statistically significant.

The aggregate additional kilometres flown due to industrial actions is much larger than the additional kilometres flown due to technical failures. These results lend support to the current policy attention for air network service continuity during ATC strikes (e.g., European Commission, 2017). Given that the flight efficiency impact of industrial actions is concentrated in areas where overflights are not guaranteed, our results suggest that EU-wide minimum service requirements for overflights could be an effective policy to ensure the efficient functioning of the European air transport network during industrial actions.

Due to data limitations we could not include intercontinental flights nor consider the impacts on vertical flight efficiency. Our analysis also does not take into account potential knock-on effects to adjacent airspace sectors and/or days. These extensions are left for further research to explore.

References

Angrist, J. D. and Pischke, J.-S. (2009). *Mostly Harmless Econometrics*. Princeton University Press, New York.

BBC (2013). French air traffic strike grounds UK flights. Retrieved October 30, 2019, from https://www.bbc.com/news.

Blondiau, T., Glazer, A., and Proost, S. (2018). Air traffic control regulation with union bargaining in Europe. *Economics of Transportation*, 13:48–60.

Brueckner, J. K. and Abreu, C. (2017). Airline fuel usage and carbon emissions: Determining factors. *Journal of Air Transport Management*, 62:10–17.

Button, K. and Neiva, R. (2013). Single European Sky and the functional airspace blocks: Will they improve economic efficiency? *Journal of Air Transport Management*, 33:73–80.

Caliendo, M. and Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, 22(1):31–72.

Cameron, C. A. and Miller, D. L. (2015). A Practitioner's Guide to Cluster-Robust Inference. *Journal of Human Resources*, 50(2):317–372.

Efthymiou, M. and Papatheodorou, A. (2018). Environmental considerations in the Single European Sky: A Delphi approach. *Transportation Research Part A: Policy and Practice*, 118:556–566.

Eurocontrol (2016). Network Operations Report 2015. Edition Number: 1.

Eurocontrol (2017). Network Operations Report 2016. Edition Number: 1.

Eurocontrol (2018). Network Operations Report 2017. Edition Number: 1.

Eurocontrol (2019). Demand data repository web portal. Retrieved January 1, 2019, from https://www.eurocontrol.int/ddr.

European Commission (2017). *Commission Staff Working Document: Practices favouring Air Traffic Management Service Continuity*. Brussels.

Horton, G. and Congdon, L. (2017). Study on Options to Improve ATM Service Continuity in the Event of Strikes. Technical report, Ricardo Energy & Environment and York Aviation.

Imbens, G. W. and Wooldridge, J. M. (2009). Recent Developments in the Econometrics of Program Evaluation. *Journal of Economic Literature*, 47(1):5–86.

PWC (2016). Economic Impact of Air Traffic Control Strikes in Europe. Technical report.

Reynolds, T. G. (2014). Air traffic management performance assessment using flight inefficiency metrics. *Transport Policy*, 34:63–74.

Rosenbaum, P. R. and Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70(1):41–55.

Rubin, D. B. (1979). Using Multivariate Matched Sampling and Regression Adjustment to Control Bias in Observational Studies. *Journal of the American Statistical Association*, 74(366a):318–328.

Ryerson, M. S., Hansen, M., and Bonn, J. (2014). Time to burn: Flight delay, terminal efficiency, and fuel consumption in the National Airspace System. *Transportation Research Part A: Policy and Practice*, 69:286–298.

Smith, J. A. and Todd, P. E. (2005). Does matching overcome LaLonde's critique of nonexperimental estimators? *Journal of Econometrics*, 125(1-2 SPEC. ISS.):305–353.

Swan, W. M. and Adler, N. (2006). Aircraft trip cost parameters: A function of stage length and seat capacity. *Transportation Research Part E: Logistics and Transportation Review*, 42(2):105–115.

The Times (2019). French air traffic control strike disrupts hundreds of flights. Retried 30 October, 2019, from https://www.thetimes.co.uk.

Travel Weekly (2015). Flights cancelled due to Italian air traffic control strike. Retried 30 October, 2019, from http://www.travelweekly.co.uk.

A Industrial actions at European ANSPs

Table A.1: Industrial actions at European ANSPs, 2015 - 2017

Date(s)	Country	Days
16 January 2015	Italy	1
17 February 2015	Italy	1
20 March 2015	Italy	1
8-10 April 2015	France	3
11/12, 25/26 July 2015	Spain	4
15 July 2015	Romania	1
5 August 2015	Greece	1
26 September 2015	Spain	1
8 October 2015	France	1
23-27 November 2015	France	5
26 January 2016	France	1
20/21/22 March 2016	France	3
31 March 2016	France	1
27/28/29[a] April 2016	France	3
19 May 2016	France	1
26 May 2016	France	1
02 June 2016	France	1
13/14/15[a] June 2016	France	3
16[a]/17 June 2016	Italy	2
23/23/24 June 2016	France	3
27/28/29[a] June 2016	France	3
4/5/6 July 2016	France	3
14/15 September 2016	France	2
06/07/08/09/10 March 2017	France	5
20 March 2017	Italy	1
12 May 2017	Romania	1
17 May 2017	Greece	1
30 May 2017	Romania	1
11/12/13[a] September 2017	France	3
21 September 2017	France	1
09/10/11 October 2017	France	3
15/16/17 November 2017	France	3
15 December 2017	Italy	1

Note(s): Based on Eurocontrol Network Operation Reports (Eurocontrol, 2016, 2017, 2018). [a]The following industrial action days were excluded from the analysis (reason in brackets): 29 April 2016 (did not affect airspace sectors), 15 and 16 June 2016 and 13 September 2017 (no regulations found in NEST), 29 June 2016 (no suitable reference day available).

B Complete estimation results

Table B.1: Complete model estimation results, 2015, 2016

	Time trend (β)			Efficiency impact (γ)		
	Coef	Std err	p-val	Coef	Std err	p-val
Italy 16-1-2015	-0.319	0.921	0.729	-2.382	1.544	0.123
Italy 17-2-2015	-0.624	1.327	0.638	0.416	1.889	0.826
Italy 20-3-2015	1.165	1.109	0.294	-2.959	1.700	0.082
France 8-4-2015	-0.247	0.958	0.797	54.054	3.092	0.000
France 9-4-2015	-0.037	0.749	0.960	40.976	2.863	0.000
France 10-4-2015	1.437	0.746	0.054	2.099	1.169	0.073
Spain 11-7-2015	1.538	1.098	0.162	-1.695	1.701	0.319
Spain 12-7-2015	-5.561	2.308	0.016	5.540	3.769	0.142
Spain 25-7-2015	-2.373	1.346	0.078	-0.051	1.876	0.978
Spain 26-7-2015	5.283	3.260	0.106	2.108	4.269	0.622
Romania 15-7-2015	-7.372	1.844	0.000	4.820	2.898	0.097
Greece 5-8-2015	-0.107	0.936	0.909	2.328	1.243	0.061
Spain 26-9-2015	-0.950	2.772	0.732	3.784	3.728	0.310
France 8-10-2015	-5.875	0.766	0.000	24.127	1.817	0.000
France 23-11-2015	1.712	1.235	0.166	17.900	2.424	0.000
France 24-11-2015	0.455	1.437	0.751	11.774	2.840	0.000
France 25-11-2015	1.112	1.113	0.318	13.504	2.453	0.000
France 26-11-2015	0.330	1.357	0.808	12.170	2.627	0.000
France 27-11-2015	0.245	1.506	0.871	11.846	2.619	0.000
France 26-1-2016	1.072	0.927	0.248	33.799	2.926	0.000
France 20-3-2016	-3.510	0.996	0.000	70.666	3.682	0.000
France 21-3-2016	-2.809	1.016	0.006	75.438	4.243	0.000
France 22-3-2016	-2.183	1.815	0.229	4.364	2.057	0.034
France 31-3-2016	-2.744	0.864	0.002	42.064	2.749	0.000
France 27-4-2016	-4.550	1.596	0.004	22.230	2.341	0.000
France 28-4-2016	-6.067	0.878	0.000	35.490	2.370	0.000
France 19-5-2016	-5.561	0.898	0.000	37.733	2.286	0.000
France 26-5-2016	-4.106	0.936	0.000	28.122	2.185	0.000
France 2-6-2016	-0.439	0.759	0.563	14.189	1.620	0.000
France 13-6-2016	-0.821	1.337	0.539	17.615	2.053	0.000
France 14-6-2016	-1.031	0.966	0.286	25.388	2.185	0.000
Italy 17-6-2016	1.970	0.896	0.028	2.152	1.313	0.101
France 22-6-2016	-2.051	1.106	0.064	6.783	1.668	0.000
France 23-6-2016	1.984	0.832	0.017	14.980	1.816	0.000
France 24-6-2016	-2.479	2.413	0.305	1.421	3.589	0.693
France 27-6-2016	3.322	0.880	0.000	12.081	1.798	0.000
France 28-6-2016	2.579	0.501	0.000	13.509	1.481	0.000
France 4-7-2016	0.251	1.013	0.805	-2.007	2.234	0.369
France 5-7-2016	-1.695	0.665	0.011	7.448	1.379	0.000
France 6-7-2016	1.882	2.681	0.483	1.387	4.008	0.730
France 14-9-2016	-4.049	0.949	0.000	8.835	1.491	0.000
France 15-9-2016	0.743	0.789	0.346	10.200	1.388	0.000

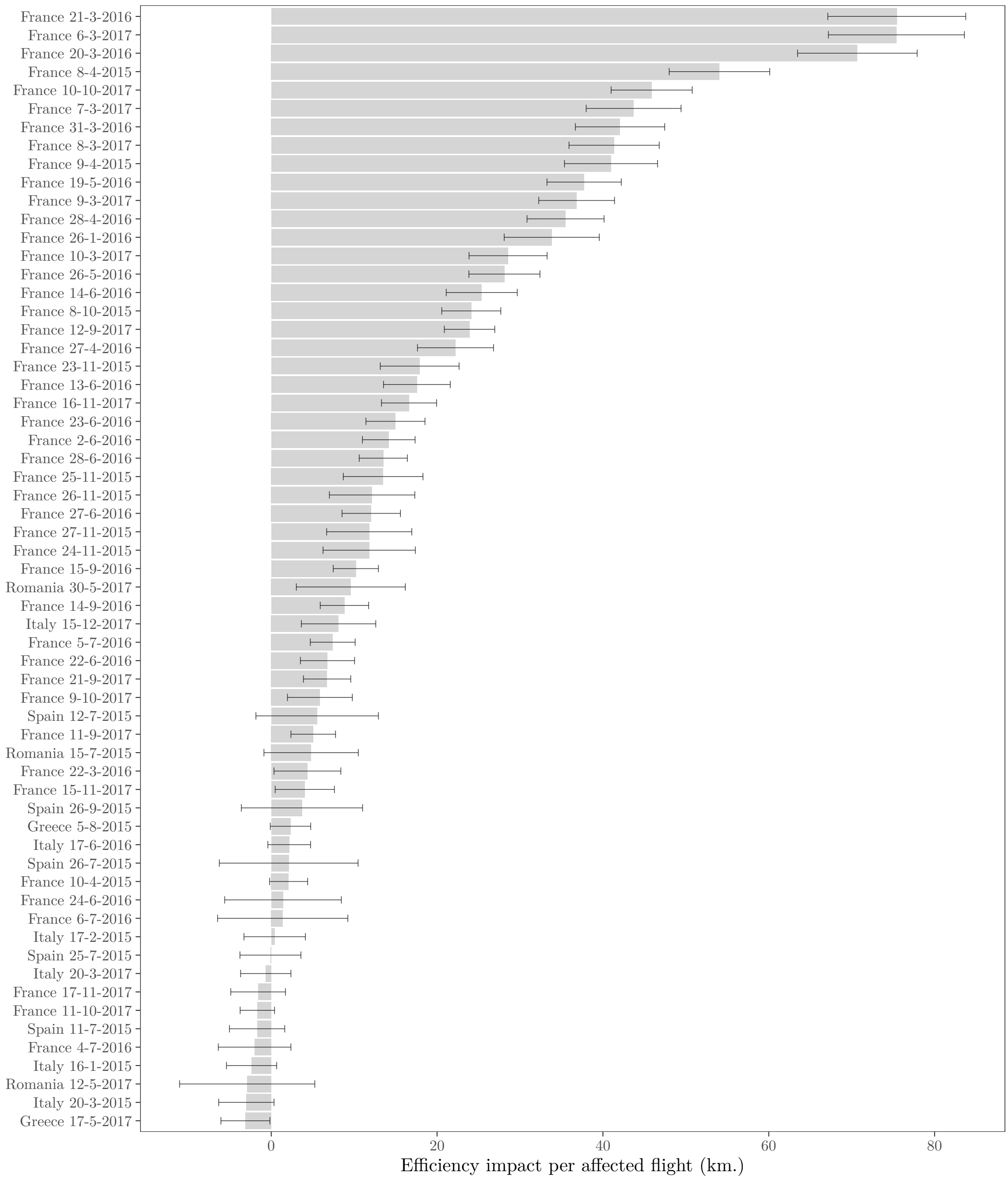
Note(s): Robust standard errors, clustered by routes.

Table B.2: Complete model estimation results, 2017

	Time trend (β)			Efficiency impact (γ)		
	Coef	Std err	p-val	Coef	Std err	p-val
France 6-3-2017	-0.596	1.641	0.716	75.373	4.184	0.000
France 7-3-2017	0.796	1.097	0.468	43.703	2.919	0.000
France 8-3-2017	-1.184	0.704	0.093	41.349	2.775	0.000
France 9-3-2017	-0.100	0.757	0.895	36.833	2.330	0.000
France 10-3-2017	0.310	1.002	0.757	28.563	2.402	0.000
Italy 20-3-2017	1.033	1.232	0.402	-0.674	1.548	0.663
Romania 12-5-2017	-3.167	3.213	0.325	-3.132	4.161	0.452
Greece 17-5-2017	1.519	1.185	0.200	-3.121	1.506	0.038
Romania 30-5-2017	-1.371	2.136	0.521	9.567	3.353	0.004
France 11-9-2017	2.150	0.938	0.022	5.067	1.373	0.000
France 12-9-2017	-0.287	0.676	0.671	23.909	1.552	0.000
France 21-9-2017	0.754	0.831	0.364	6.749	1.455	0.000
France 9-10-2017	-2.055	1.035	0.047	5.867	1.996	0.003
France 10-10-2017	-0.783	0.627	0.211	45.872	2.496	0.000
France 11-10-2017	-1.428	0.740	0.054	-1.678	1.059	0.113
France 15-11-2017	-3.134	1.336	0.019	4.057	1.823	0.026
France 16-11-2017	-0.486	0.687	0.479	16.618	1.696	0.000
France 17-11-2017	-1.289	0.996	0.196	-1.582	1.682	0.347
Italy 15-12-2017	-0.751	1.403	0.592	8.118	2.290	0.000

Note(s): Robust standard errors, clustered by routes.

Figure B.1: Flight efficiency impacts per industrial action



Note(s): Height of bars equals estimated flight efficiency impact; error bars show the 95% confidence intervals.

C Sensitivity analyses

Table C.1: Estimation results sensitivity analyses

	Baseline model								
	(1) Major airlines			*(2) Censored*			*(3) Overflights*		
	Coef	Std err	p-val	Coef	Std err	p-val	Coef	Std err	p-val
Average ($\overline{\gamma}$)	10.618	0.247	0.000	9.211	0.255	0.000	16.932	0.355	0.000
Minimum ($\min \gamma_j$)	-7.987	3.681	0.030	-5.086	4.604	0.270	-18.964	18.934	0.343
Maximum ($\max \gamma_j$)	74.662	4.093	0.000	62.786	4.505	0.000	134.873	6.861	0.000
Industrial action days		61			61			60	
Flight observations		786,524			693,978			468,106	

Note(s): Robust standard errors, clustered by routes.

Table C.2: Estimation results for placebo test

	Baseline model		
	Coef	Std err	p-val
Average ($\overline{\gamma}$)	-0.003	0.198	0.990
Minimum ($\min \gamma_j$)	-15.436	3.861	0.000
Maximum ($\max \gamma_j$)	9.137	2.481	0.000
Industrial action days		61	
Flight observations		798,536	

Note(s): Robust standard errors, clustered by routes.

Table C.3: Estimation results matching procedures sensitivity analyses

	Baseline model								
	(1) Maximum distance			*(2) With replacement*			*(3) Optimal*		
	Coef	Std err	p-val	Coef	Std err	p-val	Coef	Std err	p-val
Average ($\overline{\gamma}$)	9.552	0.247	0.000	10.848	0.261	0.000	10.853	0.246	0.000
Minimum ($\min \gamma_j$)	-5.506	3.808	0.149	-3.389	1.780	0.057	-10.283	4.018	0.011
Maximum ($\max \gamma_j$)	65.271	4.352	0.000	75.746	4.325	0.000	76.683	4.019	0.000
Industrial action days		61			61			60	
Flight observations		786,524			693,978			468,106	

Note(s): Column (1) restricts the maximum propensity score distance between matched pairs. Column (2) allows for matching with replacement such that a single unaffected route can serve as match for multiple affected routes. Column (3) applies optimal matching which instead of choosing matches one at a time, minimizes the absolute distance across all matched pairs. Robust standard errors, clustered by routes.

seo amsterdam economics

Roetersstraat 29 . 1018 WB Amsterdam . T (+31) 20 525 16 30 . F (+31) 20 525 16 86 . www.seo.nl