Quantifying the Causal Impact of Airport Capacity Expansion on Delay

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SHORT SUMMARY

This paper quantifies the causal impacts of improved gate and runway capacity on airport delay. To estimate the causal effects, it applies a synthetic control method to data on Miami International Airport (MIA) and Fort Lauderdale–Hollywood International Airport (FLL). The results show that the gate capacity expansion in MIA airport substantially relieves departure delay, arrival delay, and taxi-in delay, however, it has no effect on taxi-out delay. The runway capacity expansion of FLL airport results in more than 10-15% decline in departure and arrival delay during peak months and a 30-50% decrease in taxi-out delay, while increasing taxi-in delay. Given the considerable cost of airport delay and new airport infrastructural investments, these results are of high importance for airport operators and government decision-makers to plan such investments.

Keywords: airport capacity, airport delay, causal analysis, synthetic control method

1. INTRODUCTION

In the last decade before COVID-19, the imbalance between growing airport demand and limited capacity had caused severe airport congestion and delay. Such delays may have several negative impacts, such as disrupting passengers' travel plans, causing extra operational expenses for airports and airlines, and increasing the emission of greenhouse gas (Zografos et al., 2013). The delays in local airports often propagate to connecting airports and even the whole airport system through connecting flights (Pyrgiotis et al., 2013). Therefore, the airport congestion problem has widely drawn the attention of airports, airlines, and governments.

To relieve airport congestion, decision-makers often control airport demand by setting limits to slot arrangements (Wells, 1992) or enhancing airport capacity by investing in new operational technologies, such as Airport Surface Detection Equipment Model X (ASDE-X), Traffic Flow Management System (TFMS), Airport Collaborative Decision-Making (A-CDM) (Janić, 2017), or in new infrastructures, such as new terminals, runways, rapid exit taxiways, etc. (Janić, 2000). Many large hub airports, such as Heathrow Airport (LHR) and Hong Kong Airport (HKG), are also constructing a new runway by 2030 to serve more flights in the future. New terminals are built to provide more gates and landside facilities that can accommodate more flights and passengers. For instance, HKG introduced a new midfield concourse in 2016, providing 20 additional parking stands and serving an excess of 10 million passengers annually (Hong Kong International Airport, 2016). The overarching aim of this research is to investigate whether such investments improve airport delay performance. The capacity expansion cases studied in this paper include the extended runway project for 10R-28L at FLL Airport in 2014 and the north terminal gate capacity expansion at MIA Airport in 2013.

Background

When airports reach about 70 percent of their annual flight capacity, decision-makers may start to plan for capacity expansion because the usual timeline from planning to operation could be more than ten years (GAO, 2003). The timeline is determined by factors such as availability of funding, anticipated environmental impact and political regulations. Once the capacity expansion is introduced, the ratio of demand-to-capacity is expected to decrease and, consequently, relieve airport congestion and reduce related delays. For flight departures, runway capacity expansion may alleviate congestion during taxiing-out and queuing for take-off, thus reducing the taxi-out time and departure delay. Additionally, for flight arrivals, the following impact may be realized. Arriving flights need to queue for taxiing-in to the gate after landing. When the precedent departing flight is delayed at the gate assigned for the next arriving flight, the arriving flight has to wait until either the departing aircraft pushes back and the gate is cleared, or it is reassigned to another gate. Enhancing runway capacity may allow for the punctual departure of flights from their respective gates, thus also reducing the arrival delay at the airport. Moreover, airport congestion may also result from limited gate capacity. Enhancing airport gate capacity may relieve congestion at the gates and improve both arrival delay and taxi-in time. If the precedent flights arrive on time, the following flights are more likely to depart on time. Thus, gate capacity enhancement may also decrease departure delay.

The literature examines both ex-ante and ex-post effects of airport capacity expansion. Numerous ex-ante studies evaluate the potential benefits of airport capacity expansion via analytical simulation models, such as cost-benefit analysis (Jorge and de Rus, 2004), utility-based methodology (Wei, 2008), supply-demand equilibrium analysis (Zou and Hansen, 2012), Analytic Hierarchy Process (AHP) (Zietsman and Vanderschuren, 2014), and Simple Additive Weighting (SAW) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Janić, 2017). However, the impact predicted by such studies may be limited because of the underlying uncertainty in anticipating future demand, environmental performance control, and other political regulations. For instance, although the Düsseldorf International Airport (DUS) constructed a second runway in 1993, it was never permitted to use the runway due to restrictions on greenhouse gas emissions (Dray, 2020).

On the contrary, ex-post analyses provide insights that are derived from observed data. Such insights could be more appropriate to guide adjustments in potential capacity expansion plans or even motivate capacity expansion at other airports. However, the ex-post evidence in the literature remains limited (Hansen, 2004; Hansen and Wei, 2006; Wei and Hansen, 2006; Woodburn and Ryerson, 2014; Hansen et al., 1998; Dray, 2020). These studies are with major focus on runway capacity. Moreover, we note that previous empirical studies mostly rely on a simple before-and-after comparison to quantify the impact of airport capacity expansion. We argue that such estimates may suffer from confounding biases caused by temporal trends or extraneous factors, such as seasonal differences in air travel demand, unrelated to the intervention. Furthermore, the treatment assignment (that is, airport capacity expansion) may be non-random and rather conditional on factors such as the number of aircraft movements, which further exacerbates the confounding issue.

Contributions

To address the above-discussed confounding biases, this study uses a synthetic control analysis to quantify the causal impact of airport capacity expansion on airport delay. The idea is to understand the impact of the intervention on the treated unit with respect to a synthetic counterfactual unit unaffected by the intervention in the post-treatment period. We assess the impact of airport capacity expansion in terms of both runway capacity and gate capacity via two case studies comprising the FLL and the MIA airports.

2. DATA AND METHODOLOGY

Data

We consider two case studies: (1) the runway capacity extension for 10R-28L at the FLL airport introduced in September 2014 (Parsons, 2013), and (2) the north terminal gate capacity expansion at the MIA Airport introduced in 2013. We use monthly data on airport operations for 30 US core airports from the ASPM database for 2009-2016 (Federal Aviation Administration). The data reports operational attributes such as Scheduled Departures, Scheduled Arrivals, Average Gate Departure Delay, Average Taxi Out Time, Average Taxi Out Delay, Average Airborne Delay, Average Taxi In Delay, Average Gate Arrival Delay. The number of passengers for US airports is obtained from TranStats (Bureau of Transportation Statistics).

To quantify the causal effect of airport capacity expansion on airport delay, we define the essential elements for causal analysis, including treatment, outcome, and covariates. The treatment is defined as whether or not the airport begins operation of new infrastructure during 2019-2016. The measures for airport delay performance in terms of departure delay, arrival delay, taxi-out delay, and taxi-in delay, are the outcome variables in our model. The covariates in our model include the number of aircraft movements, number of passengers, an indicator of whether the airport is a hub airport (refer to the following sub-section for details).

Synthetic control method (SCM)

We use the synthetic control method (SCM) to assess the causal impact of airport capacity expansion on airport delay. The SCM allows us to generate post-treatment counterfactual trends for the treated unit via a synthetically derived control unit. To derive the control unit, we conceptualize a weighted average of untreated US large hub airports, that is, those without any major infrastructural changes in the post-treatment period. The impact of airport capacity expansion is evaluated by comparing the actual airport delay performance of the treated unit and the weighted average of airport delay of such synthetic control unit.

One of the key assumptions underlying the SCM is that the treatment is exogenous to the outcome of interest. The suitability of the SCM to our case follows a strong assumption that the airport's decision to expand its capacity is not influenced by the level of congestion in the system. Following Zou and Hansen (2012), we argue that the aviation infrastructure investment is volatile and often conditional on several public, political, economic, and environmental factors. Thus, the airport delay performance may have a weak link to capacity investment.

Let J be the number of potential control units, and $\boldsymbol{W} = (w_1, w_2, \dots, w_J)'$ be a $(J \times 1)$ vector of non-negative weights for all potential control units such that $\sum_{\boldsymbol{J}} \boldsymbol{w_j} = 1$. The SCM aims to choose the best $\boldsymbol{W}^*$ by minimizing (1) so that the synthetic control unit resembles the treated unit in the pre-treatment period.

$$\text{Min}_{\boldsymbol{W}} \ (\boldsymbol{X_1} - \boldsymbol{X_0 W})' \boldsymbol{V} (\boldsymbol{X_1} - \boldsymbol{X_0 W}), \ st. w_j \geq 0 \ and \ \sum_{j=1}^{J} w_j = 1 \quad (1)$$

$\boldsymbol{X_1}$ is a $(K \times 1)$ vector of delay predictors for the treated airport in the pre-treatment period. $\boldsymbol{X_0}$ is a $(K \times J)$ matrix containing the values of these predictors for the J potential control units. $\boldsymbol{V}$

represents a $(K \times K)$ diagonal matrix reflecting the relative importance of different predictors. To address the potential bias caused by the non-random treatment assignment, SCM minimizes the difference of predictors between the treated unit and synthetic control unit in pre-treatment period, which also shows a good parallel trend fitting for the outcome of treated unit and synthetic control unit in pre-treatment period. Once the synthetic control airport is constructed with the $\boldsymbol{W}^*$, we compare the airport delay of treated airport against the synthetic control airport, that is,

$$\boldsymbol{Y_1} - \boldsymbol{Y_0}\boldsymbol{W}^*$$

where $\boldsymbol{Y_1}$ is the $(T \times 1)$ vector of the outcome variable of interest for the treated airport at time $t: t = 1, \dots, T$ and $\boldsymbol{Y_0}$ is the corresponding $(T \times J)$ matrix of the outcome variable for J control units.

3. RESULTS AND DISCUSSION

FLL Airport - runway capacity expansion

Figure 1 shows the variation of the delay performance at FLL Airport in terms of departure delay, arrival delay, taxi-out delay, and taxi-in delay. The first red line corresponds to the introduction of the runway capacity expansion intervention at the airport in September 2014. The second red line marks the end of one year since the intervention. We note that runway capacity expansion causes a minor reduction in the departure delay during peak months with high traffic volume. The first post-treatment year consists of seven months with a more than 15% decrease in the departure delay, including Sept 2014, Oct 2014, Dec 2014, Jan 2015, May 2015, June 2015, July 2015. In October 2014, the departure delay of the treated airport was 21.76% less than the synthetic control airport. In addition, arriving flights also experience a significant decrease of more than 10% in the arrival delay during peak months. In December 2014, the arrival delay for the treated airport was 19.07% less than the synthetic control airport. Further, Figure 2 indicates a significant reduction in the taxi-out delay. Most months show a 30-50% decrease within the first year since the new infrastructure was introduced. In contrast, Figure 2 suggests that the runway capacity expansion significantly increases the taxi-in delay.

MIA Airport - gate capacity expansion

Figure 3 shows that both the departure and the arrival delay decrease substantially during peak months post introduction of the intervention. Within the first year after the intervention, our results suggest a decrease of more than 15% in the departure delay in most of the peak months with high air traffic volume, including Mar 2013, Jun 2013, Jul 2013, Aug 2013, Dec 2013, Jan 2014, Feb 2014. The percentage change in the departure delay in December 2013 is 46.47%. During the above peak months, the arrival delay also shows a more than 15% reduction, however, the average percentage gap for the peak months is around 20% lower than the departure delay. From Figure 4, we note that the gate capacity expansion does not significantly improve taxi-out delay, while the taxi-in delay performance is improved. Within the first year, most of the months have a more than 20% decrease in taxi-in delay, with January 2014 showing the maximum reduction with 46.54%.

Figure 1: FLL Airport – Departure/Arrival Delay

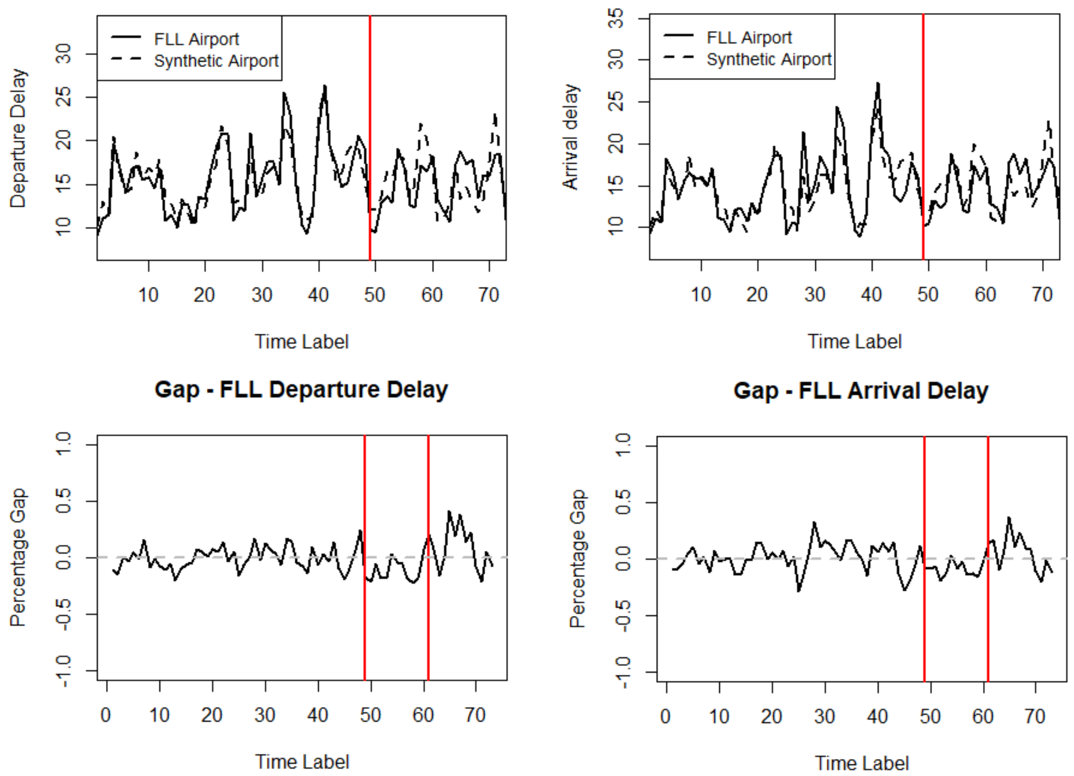


Figure 2: FLL Airport – Taxi Out/In Delay

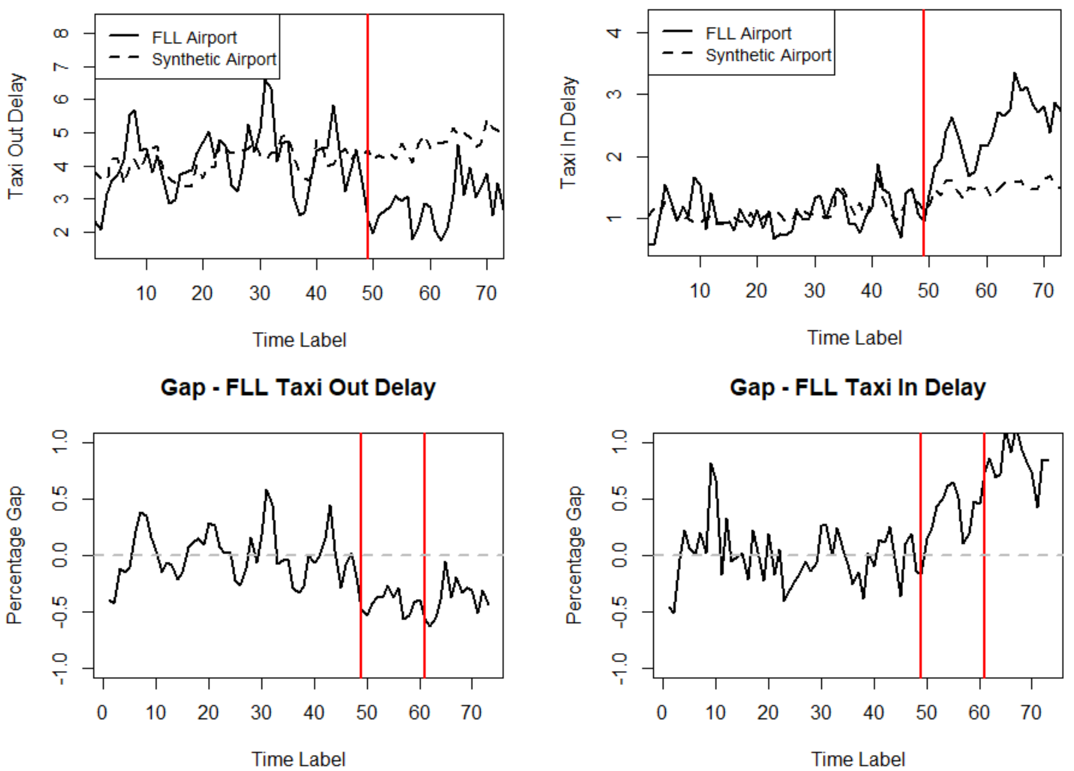


Figure 3: MIA Airport – Departure/Arrival Delay

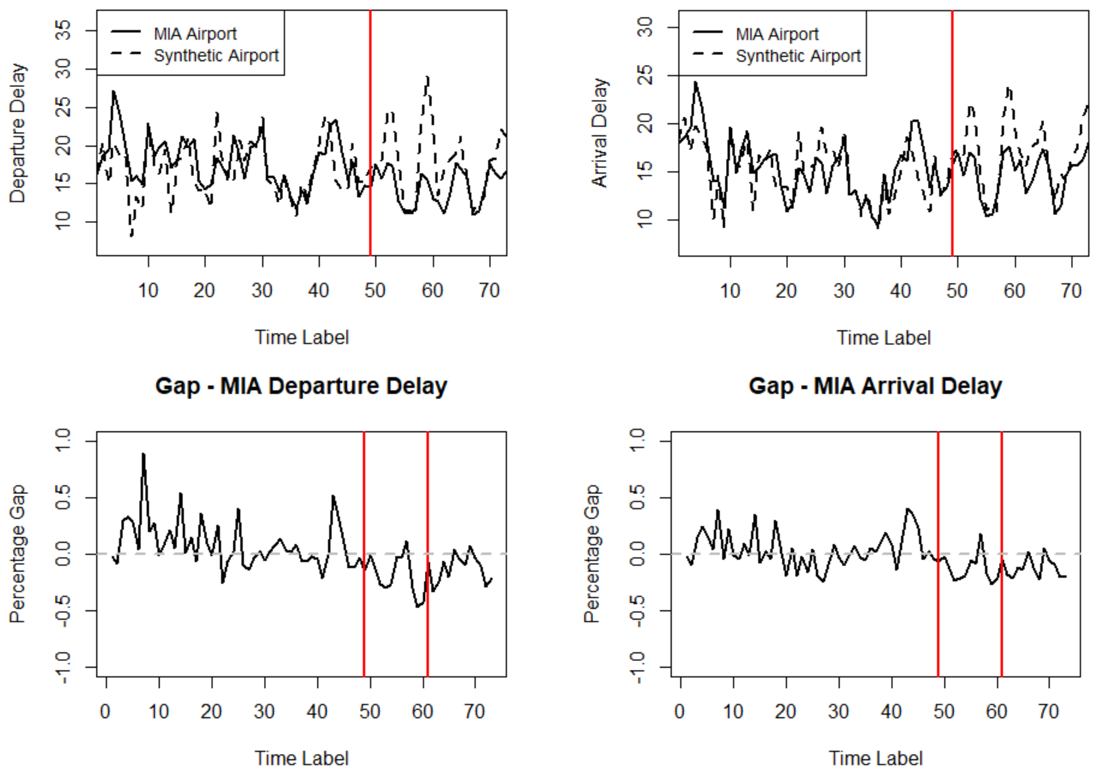
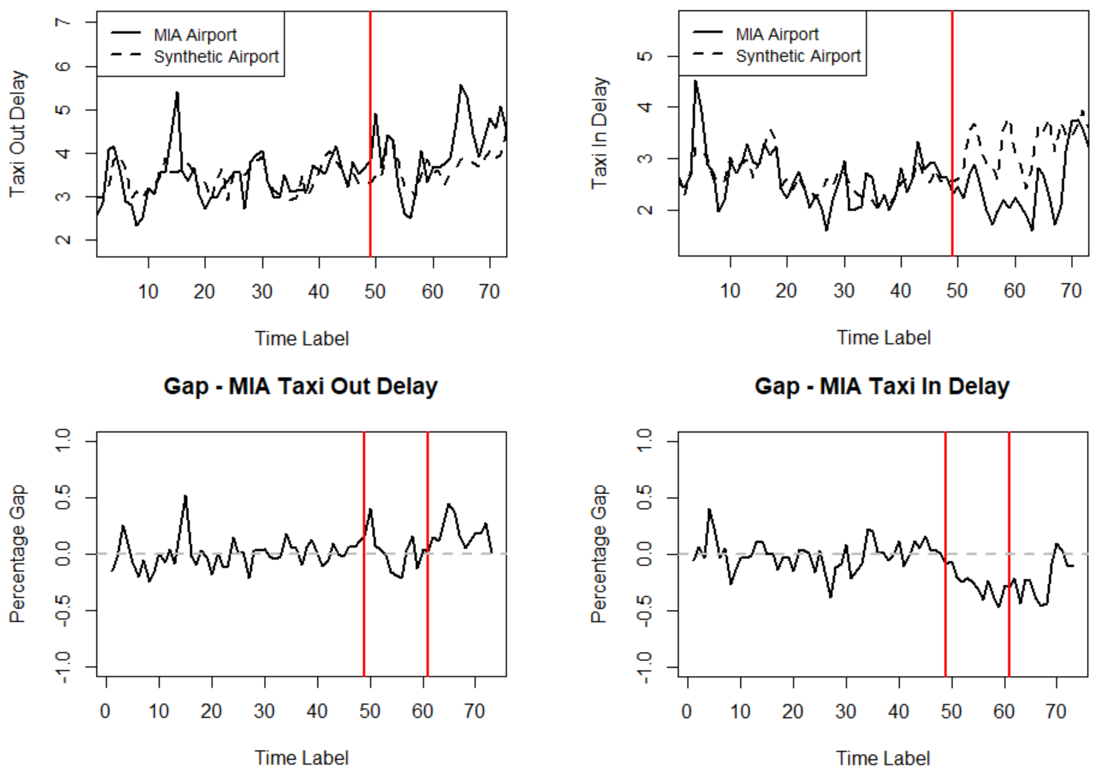


Figure 4: MIA Airport – Taxi Out/In Delay



4. CONCLUSIONS

This paper has quantified the impact of airport capacity expansion on airport delay via two case studies, (1) the FLL Airport runway expansion in 2014 and (2) the MIA Airport gate capacity expansion in 2013. We note that previous ex-post analyses investigate such impacts via a simple before-and-after comparison that does not adjust for potential confounding bias arising from external factors, temporal trends, and non-random assignment of the treatment. In this paper, we use a synthetic control method (SCM) to generate a synthetic airport that delivers the counterfactual trends for the treated airport in the post-treatment period. Our results for the FLL Airport runway capacity expansion suggest that both departure delay and arrival delay during peak months decrease by 15% relative to the synthetic control airport. In addition, the intervention also results in a significant decline in the taxi-out delay, however, it increases taxi-in delay. The gate capacity expansion in the MIA substantially relieves departure delay, arrival delay, and taxi-in delay, while suggesting no statistically significant improvement in taxi-out delay.

Note that the current work is based on the assumption that the treatment is exogenous, that is, airport delay does not cause investment of airport capacity. While this assumption may hold for airports that primarily focus on customer experience and satisfaction as argued in some previous studies, generalization of this assumption seems unreasonable. Therefore, we aim to extend this work by relaxing the exogenous treatment assumption and developing a model that is more generalized.

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