CITADEL

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Triple Threat: An Empirical Analysis on the Influence of Climate, Compounding, and Crisis on Airline Abandonment of Rural and Small Towns in the United States

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Research Motivation

In October 2021, the city of Williamsport, Pennsylvania, witnessed the departure of a commercial flight for the last time [1]. With the exit of American Airlines — the only remaining carrier serving Williamsport Regional Airport — the city of almost thirty thousand people found itself grounded [2].

The ramifications are expected to be damning. With the shortage of specialty surgeons across the country, healthcare providers in rural and small towns have increasingly resorted to enlisting traveling physicians to meet the needs of residents [3]. For Williamsport, however, the nascent lack of flights is predicted to be prohibitive of quality medical care [1].

The city isn't alone. **In the past few years, more than three hundred and twenty-four airports have seen cuts in service.** In addition, at least fourteen airports have lost service entirely [4].

For millions of individuals across the United States, air service isn't just an economic lifeline, but also a human one too. How, then, can we ensure that communities have the air service they need? Our study seeks to become the first analysis to shed light on both the factors that predict route termination and the real-world ramifications of such events.

Key Findings

We employed random forest models, principal component analysis (PCA), synthetic control methods (SCM), difference-in-difference (DID) modeling, and regression analysis to derive four main insights.

Fares See Compounding Effect

The current literature is rife with anecdotal accounts of a vicious cycle between high fares and low demand in rural and small-town airports [7]. Empirical analysis of this phenomenon, however, has been lacking. **We provide the first quantitative evidence for this theory.** Namely, we find that discontinued routes see significantly higher fares in the latter years of their service when benchmarked against the industry average.

Climate Plays Potential Role

In March 2023, NASA's Jet Propulsion Laboratory detailed the impact of rising temperatures and a less dense atmosphere on the conditions necessary for airplane lift [9]. **We present the first initial evidence in support of the impact this trend has had on route terminations.** Specifically, we find that, on average, terminated routes feature temperatures more than two degrees Fahrenheit higher than those of non-terminated routes regardless of origin. While this chasm in temperature is significant and suggestive, further investigation can provide a more nuanced understanding of this result.

Crisis Sentiment Has Little Impact

Does abstract sentiment, more strict data, or a mix impact flight attrition? We find this not to be the case – **the process for deciding which routes to terminate seems to have no exposure bias, which leads us to believe it is primarily based on profitability-centered metrics.**

Rural and Small Towns Suffer Most

While ample empirical data support the disparate impact of route eliminations on rural and small towns, we utilize robust methods to confirm these hypotheses. **Specifically, we find that having fewer passenger amounts is the largest predictor for route elimination.** As such, smaller airports tend to have the greatest likelihood of seeing closures. **Additionally, we identify and quantify the real economic harm for the surrounding locality after a route termination.**

Policy Recommendations

Drawing from both policy research and our statistical analyses, we propose a two-pronged solution. First, we recommend greater incentives for airline carriers to establish community partnerships with rural and small towns to expand base coverage. Second, we encourage the targeted expansion of federal subsidies for rural and small-town airports through the Essential Air Service program to help mitigate fare spirals.

Literature Review

The corpus of current literature has thus far focused on the benefits communities experience when they receive air service as well as the causes and impacts of flight delays and cancelations. **We seek to expand upon this domain of research twofold by tackling several gaps within the space.**

First, while the effects of air service establishment are well documented, **analyses of the immediate and long-term ramifications of air service removal are comparatively sparse** [10, 11]. As such, we aim to investigate the economic impacts of both temporary closures and permanent departures of airlines from different airports.

Second, existing research has overwhelmingly clustered around determining the preeminent causes of individual flight delays and cancelations [12, 13]. **Inquiry into the more long-term topic of entire flight routes has been lacking.** Therefore, we seek to establish preliminary empirical examination into this field by investigating various currently anecdotal factors influencing the termination of flight routes themselves. **We will utilize the term *route attrition* throughout this report to describe this loss of some or all of the routes that service a particular airport.**

Exploratory Data Analysis

The science of navigating airlines may be more akin to astrology than astronomy, with internet sources championing tips varying from booking flights during certain time periods to even using different internet browsers. In order to better understand the motivations behind air service to various markets, however, horoscopes must be put aside, and the underlying pricing model utilized by airlines needs to be thoroughly investigated.

To explore the pricing strategies employed by domestic airlines, we initially utilized scatter plot analysis to search for general trends in flight pricing. **We then stratified our data for flights into two groups: large markets and small markets.** We define large markets as flights that average at least 100 daily passengers and small markets as flights that average under 100 daily passengers.

Through time series analysis, we then sought to hypothesize various reasons for route attrition in small markets. Throughout our analysis, we primarily focused on the seven largest domestic airlines (in descending order) by the number of passengers serviced: American Airlines, Delta Air Lines, Southwest Airlines, United Airlines, Alaska Airlines, JetBlue Airways, and Spirit Airlines. **By nature of these seven companies serving the overwhelming majority of small market flights, this data allowed us to draw more powerful and statistically significant conclusions.**

Using given data on flight fares in 2017, we were able to calculate the average fare customers paid by distance serviced. For example, we obtained the following scatterplot for Delta Airlines.

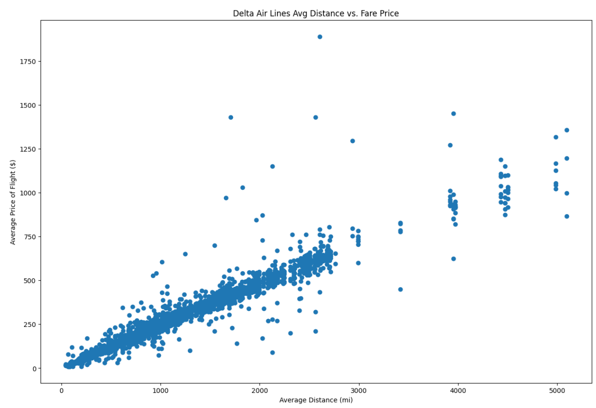

Figure 1: Average Fare Price by Distance

In general, all airlines with sufficient flight data exhibited a similar linear relationship between the distance of a flight and the average fare charged for that flight.

Next, we shifted our initial analysis to compare the difference between pricing models for large and small markets. Using a larger and more comprehensive dataset, we utilized time series analysis to ascertain the average flight fare for every major airline in the United States [22]. **We hypothesized based on our prior analysis that airline fares are derived from a fixed fare and a variable cost-per-mile addendum.**

When analyzing airline cost-per-mile pricing, we found that major domestic airline carriers generally price their small market flights similarly to their large market counterparts, albeit at an upcharge. **Utilizing linear regressions, we were able to model the cost-per-mile and fixed cost for every major airline.** For example, we found the following trends in Delta's cost-per-mile and fixed pricing for large and small markets.

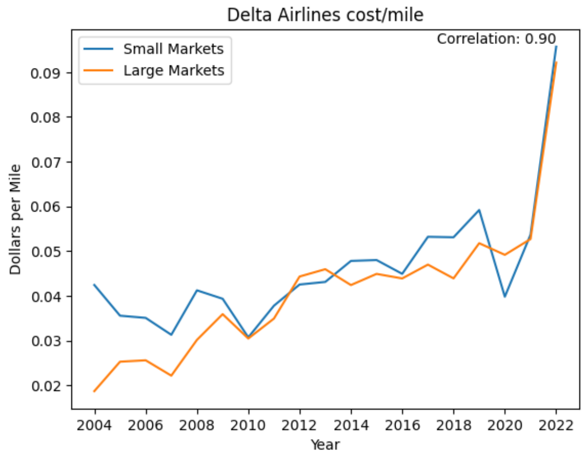

Figure 2: Cost/Mile Over Time

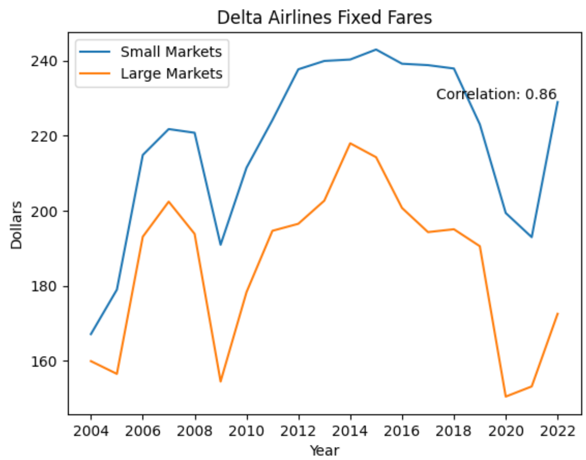

Figure 3: Fixed Fares Over Time

While the cost-per-mile charge is rather similar regardless of the size of the market, small markets operate consistently at a substantially higher fixed cost. **These findings were consistent across all seven major airlines in the United States.**

Interestingly, the correlation between the large and small market pricing models was strongest for the largest domestic airlines and gradually worsened for smaller airlines. In fact, for the smallest two domestic airlines we analyzed, JetBlue and Spirit, there is virtually no positive correlation in pricing models between small and large markets.

This can be explained by the fact that JetBlue and Spirit have virtually left the small market industry. For example, while Delta Airlines has serviced 4.3 million passengers since 2004, Jet Blue and Spirit have only serviced 28,000 passengers each. As such, we should expect to see less clear trends for airlines with less small market activity by virtue of higher variance in the data.

Relevant Insights

Based on our initial data analysis, we drew several key conclusions and hypotheses.

1. Airline pricing can be primarily split into two components: a fixed portion and a cost-per-mile portion.

2. Small markets consistently command higher fares, mainly due to a higher fixed cost. Combined with the fact that the 6th and 7th largest U.S. airlines, each of which pulled in over $14 billion in revenue in 2022, have essentially vacated this market, we posit that small markets operate at a much lower margin than large markets and require a higher cost-per-mile rate to stay profitable. **Thus, we hypothesize that there should exist a positive trend in prices, indicating declining profitability, before a flight is ultimately terminated.**

3. Small markets are sensitive to changes that impact profitability given that they already exist within thin operating margins. **As such, we posit that environmental factors such as changing weather patterns or frequency of natural disasters can sufficiently impact a flight's profitability to warrant termination.**

Inquiry Background

In late December 2022, thousands of holiday travelers were left stranded at airports across the United States due to mass delays and cancelations from Southwest Airlines.

Not long after, flights from other airlines such as United and American began appearing at significant cost premiums, including a flight from San Diego to Orlando costing upward of $2,000, a number that quickly spread across social media and sparked widespread anger [23].

While United and American were eventually forced to impose a price cap to quell public outrage on their predatory pricing, this incident highlights that airlines are fundamentally corporations first and carriers second. **As such, analyzing flight fares directly can speak to the underlying financial motivation and basis behind phenomena such as route attrition in various markets.**

Statistical Methodology

As previously hypothesized, we believe that there should exist an upward trend in flight fares in the time leading up to a flight's termination. These rising fares should indicate decreasing profitability which, beyond a certain threshold, ultimately leads to the termination of the flight route.

To provide quantitative evidence in support of this theory, we first filtered our fare dataset to only include flights that existed in prior quarters but are not reflected in later quarters. We also measured the number of quarters prior to termination that a flight route had existed. **We define *legacy routes* as routes that had or have existed for at least 4 sequential quarters.** By filtering for legacy routes, we eliminate seasonal flights (e.g. flights to Aspen, Colorado during ski season) and allow for analysis of more meaningful trends in flight fares prior to termination.

Due to the robustness of available data in this particular section of our analysis, however, we will utilize a threshold of 8 sequential quarters to further improve the rigor of our analysis. In particular, after further filtering these terminated flights to only include routes that had been in operation for at least 8 consecutive quarters, we synthesized a final dataset of over 2,300 terminated flights since 1996.

Next, before examining the trend of flight fares, we first benchmarked every fare data point as a percentage above or below the industry average fare for a data point's year and quarter. **This allowed us to control for general economic or industry trends, as well as seasonal trends in flight fares.**

By going back through the initial fare dataset, we were also able to extrapolate flights that have never been terminated since their creation to serve as a control group to our experimental group of terminated flight routes**. This control group was likewise benchmarked.**

By running regression models on every instance in both groups, we were able to identify the general trend of fares in each. Moreover, by calculating the standard deviation, we were also able to analyze the variance in flight fares for both groups.

Regression Results

After running linear regression models on both the experimental and control groups, we were able to display the frequency of various slopes returned by the regression models. The unit change in time utilized by the model was a calendar year quarter. Thus, a slope of 0.01 would indicate a quarter-over-quarter average change of 1% gain in fares against the industry average.

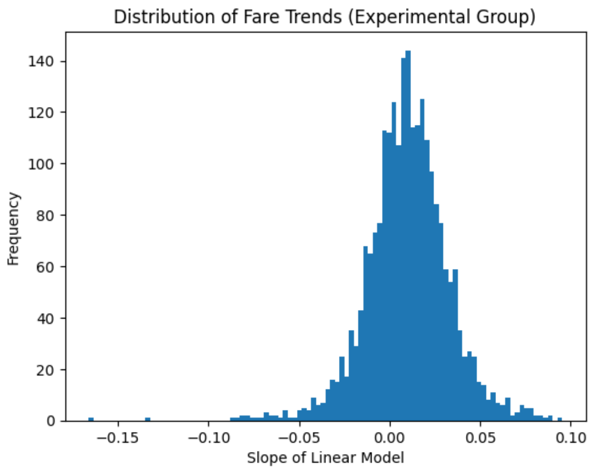

Figure 4: Distribution of Terminated Route Fare Trends

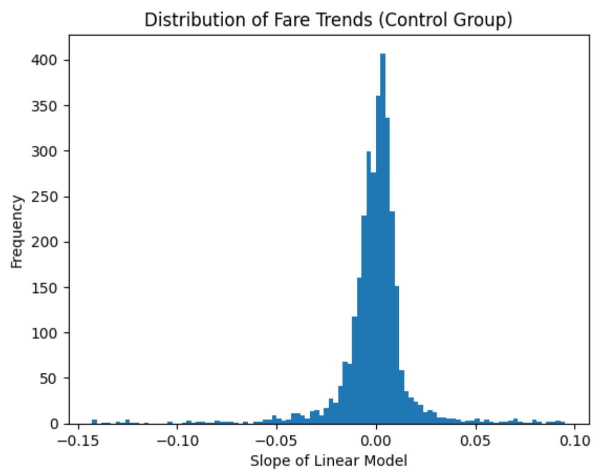

Figure 5: Distribution of Control Route Fare Trends

While the two groups appear similarly distributed, the mean of the experimental group was 0.0100 whereas the mean of the control group was -0.0008. **This indicates that fares of terminated routes averaged 1% growth against industry average in each of the 8 quarters leading up to termination, whereas flight fares for continued flights remained relatively stable and actually marginally decreased relative to industry mean.** Though the difference in these quarter-by-quarter values may seem statistically insignificant, the intrinsic compounding over 8 quarters that these numbers ultimately represent isn't.

Perhaps more interesting is that 70% of flights in the experimental group exhibited a positive trend in flight fares in the 8 quarters leading up to termination, while only 54.5% of flights in the control group exhibited a positive trend.

Insights can also be drawn from the variance of flight fares. The slopes of the experimental group yielded a standard deviation of 0.23 whereas those of the control group had a standard deviation of 0.27. Given that the control group is larger than the experimental group by over 900 distinct data points, we can reasonably expect the standard deviation of an equally sized control group to be even larger than 0.27 by the Central Limit Theorem.

Relevant Insights

Based on our analysis, we are able to draw two main conclusions.

Fares See Compounding Effect

Our hypothesis that terminated flights are likely to exhibit an upward trend is experimentally confirmed through our statistical analysis. **About 70% of terminated flights demonstrate this upward trend prior to removal and, on average, terminated flights increase in fare price by over 8% against industry average in the 2 years prior to termination.**

This can primarily be attributed to the worsening operating margins of these flights. As shown through our initial exploratory analysis, U.S. airlines consistently price small markets at a higher rate due to lower margins and profitability. Fare increases are likely only to occur when margins dip and thereafter might spur further falling demand for these flights. **We explain the trend in rising fares prior to cancelation through a *fare-demand cycle*: low demand leads to higher fares which further lowers demand.**

Clear-Trend Routes See Candidacy

Fares leading up to canceled flights exhibit less variance than the control group of never-canceled flights. This suggests that airlines can identify flights with clear upward trends in fares as candidates for termination.

This finding can logically be explained by considering an airline's bottom line. **When flights exhibit clear trends in fare prices, the airline is more easily able to act upon that trend (including but not limited to terminating the flight route).** Thus, the control group does exhibit both theoretically and empirically higher variance than the experimental group.

Furthermore, lower variance in the experimental group also supports our theory of the fare-demand cycle. If flights often get canceled due to a cycle of rising fares and lowering demand, we should expect the experimental group to exhibit a lower variance in data due to the presence of trends we've previously identified.

Inquiry Background

As record-breaking temperatures made June 2023 the hottest month on record, hundreds of flights saw cancelations, and countless more saw delays [24, 25, 26]. With less dense air reducing crucial aircraft lift and degrading engine performance, the extreme heat didn't just impact individual people but also entire airports.

With small markets already squeezed between thin operating margins as our prior analysis showed, we posit that changing weather patterns can sufficiently influence the profitability of different flight routes to warrant withdrawal and eventual route attrition.

As such, we sought to build off descriptive evidence from NASA's Jet Propulsion Laboratory in providing the first empirical evidence in support of the relationship this trend has had on delays, cancelations, and terminations.

Statistical Methodology

As described anecdotally, changing weather patterns, particularly increasing average temperatures, seem to have a connection with delays and cancelations. This should suggest that delayed and canceled flights tend toward higher average temperatures than normal flights and that temperature can serve as a predictor for whether a given flight will be delayed or canceled.

To provide evidence in support of this theory, we first created a synthetic data set by consolidating data on airlines, airports, weather, and flight traffic.

We then took a random sampling of 100,000 distinct points within this data set to serve as training and test data for a random forest regressor to ascertain the impact of weather patterns on flight delays and cancelations.

Given the vast observational reports on the impact of weather on both delays and cancelations, we decided to analyze seven features intimately connected with weather (temperature, wind speed, elevation, visibility, wind direction, snow depth, cloud status) in addition to keeping the potentially important contexts of origin airport, destination airport, and distance.

Random Forest Results

After running random forest regression algorithms on relevant features from the 100,000 data points, we were able to display the largest factors influencing flight delays and cancelations by their relative importance.

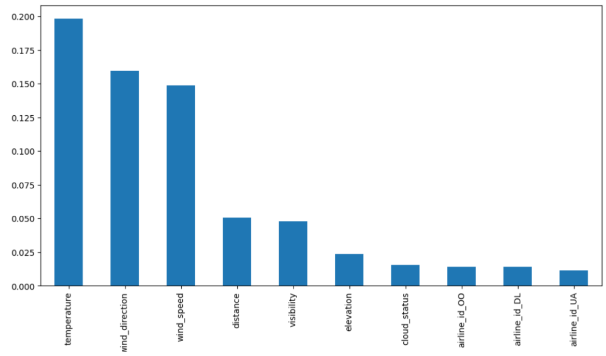

Figure 6: Predictors of Flight Delay and Cancelation

With a feature importance of 0.1982, temperature outpaces all other factors in influencing flight delays and cancelations. This was in line with our predictions as well as widespread anecdotal evidence.

It is important to note that wind direction and wind speed also seem to play an outsized role in flight delays, with feature importances of 0.1595 and 0.1488, respectively.

Other factors (distance, visibility, elevation, cloud status) do not have a significant impact.

Statistical Methodology

In addition to identifying eminent factors of flight delay and cancelation, we also tackled the dual question of whether fully terminated flights tend to see differences in temperature as a means of verifying our first result.

To achieve this, we first engineered a mapping from weather stations to the closest market region by leveraging latitude and longitude. We then excluded weather stations that did not actually fall within an encompassing market region by selecting them based on degree of proximity to their closest market region.

We then filtered unidirectional flight traffic data from 1996 to 2022 for unique flights based on a multi-index of time and flight origin and destination. From these points, we further identified routes that were terminated and those that were not. **To ensure more meaningful results, we only considered terminated routes that were legacy routes.**

Leveraging the market region data for each route, we then found the corresponding weather stations to ascertain average weather information for flight origin and flight destination. Lastly, we constructed two histograms to compare the average temperature between legacy terminated routes and non-terminated routes.

Geographic Analysis Results

Through our analysis, we were able to construct the following graphs.

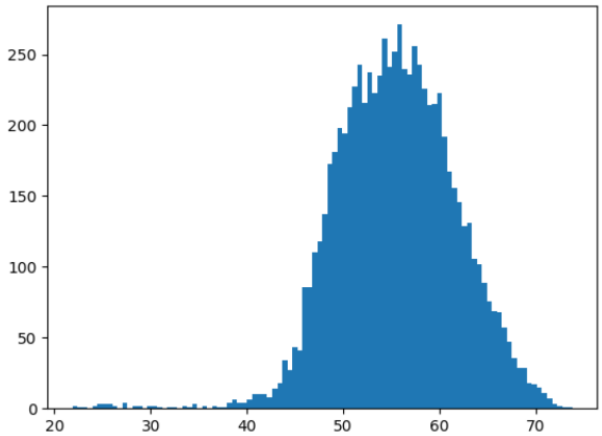

Figure 7: Histogram of Regular Route Temperatures

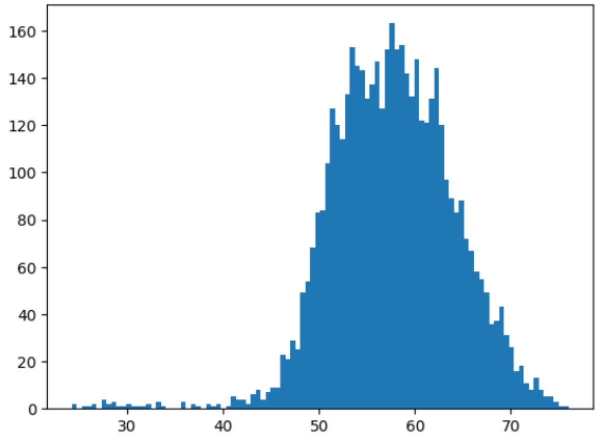

Figure 8: Histogram of Terminated Route Temperatures

The general shape and spread of both distributions are unsurprisingly similar, although terminated routes seem to see slightly higher frequency below 40 degrees Fahrenheit and above 60 degrees Fahrenheit than non-terminated routes.

Interestingly, our analysis also showed that on average, terminated routes feature temperatures more than two degrees Fahrenheit higher than those of non-terminated routes across the United States. **Whereas terminated routes had an average temperature of 57.6756 degrees Fahrenheit, non-terminated routes had an average temperature of only 55.5235.**

Relevant Insights

From our dual analysis, we are able to draw two main conclusions.

Temperature Has Predictive Power

Based on our initial random forest regression analysis, we found that **temperature, wind direction, and wind speed are the three most important factors in predicting flight delay and cancelation.**

While temperature as an eminent factor did not come as a surprise, we posit that the relevance of wind direction and wind speed may be due to the impact of significant crosswinds on the ability of aircraft to safely depart.

Routes See Temperature Disparity

Building from our random forest regression analysis, our subsequent geographic analysis into the differences between weather conditions seen in terminated routes versus non-terminated routes indicates a promising validation of our findings on the relevance of temperature as a predictor of flight delay and cancelation, events that ultimately eat into the fundamental profitability of flight routes and catalyze route attrition in the long term.

It is important to note, however, that while the chasm in temperature identified in this analysis is significant and suggestive, further investigation can provide a more nuanced understanding of this result.

Inquiry Background

What impact do public attitudes have over what routes carry over to the next quarter and which end up discarded? Climate change and generalized weather patterns yielded promising results, but we were curious about less direct factors that could influence the decision-making process within airline companies and how that could impact the termination of legacy routes. **Ultimately, we sought to understand whether the decision to remove a route was influenced by abstract sentiment, more strict data, or a mix.**

To investigate this idea, we decided to look at media reports about drastic events. **We treated exposure in the media as a proxy for how much attention people give to natural disasters.** Our hypothesis was that, given a natural disaster, one can look at the ratio of media attention to real-world costs of the disaster to understand whether sentiment plays a role in airport closures. In theory, the more often an event is mentioned in news article headlines, the more reach it has in terms of influencing sentiment. If we observe that media attention is highly connected to regional route eliminations, this may indicate that some portion of the decision-making process behind route elimination stems from empirical evidence in addition to abstract sentiment.

Ultimately, we found that the ratio between media coverage of disasters to the disaster's actual real-world cost did not have an impact on the number of flights that were canceled.

Statistical Methodology

In order to explore the factor of sentiment, **we scraped upward of 2 million news headlines stretching back to the early 1990s** from fifteen of the most frequently visited, internet-based news websites. For each news website, we accessed the robots.txt page to retrieve sitemaps, explored each of these sitemaps, and created a list of every link to every article that the news websites permitted indexing by search engines. Of the 15 news websites, every website had a portion of or the entire article title in the link which we used to count the amount of times that weather events were mentioned on by each website. We normalized this number using the number of average daily articles that each news outlet produces to find the percentage of articles per quarter that focused on individual weather events.

For our corpus of natural disasters, we leveraged the *Billion-Dollar Weather and Climate Disasters* dataset from the National Center for Environmental Information to retrieve a list of the 400 weather events which have occurred since 1990 that have caused at least $1 billion in damage.

With these data, we ran a language processor on every headline to find out whether it mentioned a natural disaster and whether the news article was published during the disaster or in the following 3 quarters — one quarter less than our definition of a legacy route — to ensure that all route terminations analyzed were in service during the disaster.

To understand the relationship between route elimination and sentiment-related decision-making, we then found the ratio of media coverage as proxied by NLP hits to the actual cost of the disaster.

The second ratio we considered was the number of route cancellations that happened benchmarked against the average rate. We found this by dividing the amount of routes that were canceled during the disaster's time frame by the average number of routes eliminated over time for the region. We weighted this average to reflect the yearly increase in total routes throughout our dataset.

We then ran a linear regression on the coverage-cost ratio against the route cancelation ratio. We analyzed the data in this way on a total as well as disaster type by disaster type basis.

Extraction Results

We found no correlation between outsized media attention and increased flight cancelations. This leads us to believe that **the process of canceling a route is evaluated primarily using profitability metrics.** While this means that abstract sentiment likely does not play a role, **this analysis strengthens our confidence in our other models that look more strictly at profitability-adjacent domains.**

Inquiry Background

From Arizona to Alaska to Alabama, rural and small-market airports have seen an overwhelming bias and burden when it comes to flight attrition [4, 5, 6, 7].

While ample aggregate anecdotal data support this sobering reality, we sought to utilize more granular methods to demonstrate it as well.

In particular, we aimed to show that rural and small-town airports are at a greater risk of flight attrition due to having less traffic and few passengers. Further, we sought to empirically illustrate the tangible economic impacts of flight attrition on the vibrance of real-life communities using synthetic control models and the difference-in-differences method.

Statistical Methodology

The current discussion is rife with articles and anecdotal accounts on the propensity for rural and small towns to see flight attrition.

In order to find empirical support for this theory, we leveraged our prior synthesized data set on legacy routes that eventually saw termination to construct a random forest regressor to extract important factors influencing route termination. **We also kept the remaining data set of all domestic flight routes since the 1990s that have not been terminated to utilize our random forest regressor to predict routes most likely to get canceled as a means of validating identified important features.**

Given our prior research into the importance of fares and demand as seen in the fare-demand cycle for smaller markets, for features, we decided to analyze the number of passengers, average market fare, average fare for the airline with the lowest fair, and average fair for the airline with the largest market share, in addition to keeping the potentially important contexts of origin state, destination state, and distance.

Lastly, in order to utilize ensemble learning methods and the decision tree framework through our random forest regressor, we converted categorical values to numeric values.

Random Forest Results

By converting the random forest regressor feature importances into an array sorted in descending order, we constructed the following chart.

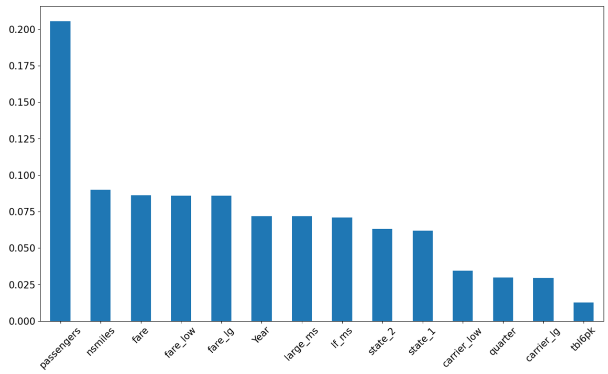

Figure 9: Feature Importances for Terminated Routes

It is immediately clear that **the number of passengers with an importance of 0.206 singly outpaces all other features in relative influence on route termination.**

The next four factors — nautical miles, average market fare, average fare for the airline with the lowest fair, and average fair for the airline with the largest market share — have similar importance, at 0.0899, 0.0869, 0.0865, and 0.0859, respectively.

Perhaps most importantly, **our random forest regressor had a relatively high accuracy of 89.47%.** To further validate the strength of the regressor's associated feature importances, we employed the trained random forest to analyze the 60,000+ flight data points that have not seen terminations.

This predictive work returned the following chart on the routes most likely to be terminated in the next two quarters given historical precedent.

city2	fare	city1	passengers	nsmiles
Sanford, FL	69.72	Austin, TX	13	994
Punta Gorda, FL	109.70	Plattsburgh, NY	14	1311
Spokane, WA	534.17	Albany, NY	12	2133
Martha's Vineyard, MA	148.40	Boston, MA (Metropolitan Area)	36	70
San Diego, CA	479.80	New Bern/Morehead/Beaufort, NC	12	2297
New Bern/Morehead/Beaufort, NC	535.37	Los Angeles, CA (Metropolitan Area)	11	2345
Portland, OR	488.03	Bristol/Johnson City/Kingsport, TN	11	2167

Figure 10: Existing Routes Likely to See Termination

For all routes except for the fourth, the number of passengers is exceedingly low. While the fourth route has a slightly higher number of passengers, it has an incredibly short flight distance in nautical miles.

As such, we see a concurrence in the predictions and the important features, validating the results of our random forest model and more broadly strengthening our initial hypothesis that rural and small-town airports are at a greater risk of flight attrition by nature of passenger traffic.

Statistical Methodology

With this knowledge of the bias toward rural and small-town communities in the occurrence of flight attrition, it is even more important to understand the real-world burden and effect that legacy route closures have on people.

To achieve this, for the second part of this section, we created synthetic control models for each industry for every county that has experienced route attrition.

Synthetic control models (SCMs) are a statistical technique used to estimate the causal impact of an intervention (e.g. airline route closure) on a treated unit (e.g. a county) by comparing it with a carefully constructed synthetic or counterfactual unit. The goal is to simulate what the treated unit's outcome would have been in the absence of the intervention and use this information to highlight how the change in environment modifies our analyzed unit's outcomes.

The SCM approach begins by selecting a set of control units that are similar to the treated unit before the intervention. These control units serve as a "synthetic" or "composite" version of the treated unit's counterfactual outcome. Control units do not experience treatment while treated units do. The key assumption is that, in the absence of the intervention, the treated unit would have followed a similar trajectory to the control units. In our case, we were analyzing data that included the change in GDP per year per industry in counties.

Our method deviates from a traditional SCM in that it uses an average control county for comparison. There are a plethora of factors that affect GDP growth rates that simply can't be accounted for. To mitigate the impact of unknown factors, we took an average of comparable counties as our control unit.

Furthermore, this average control technique limits the need for individualized placebo modeling, which helped us understand and evaluate whether the model adhered to the key parallel trends assumption.

We created a custom mean-squared-error scoring function that calculates the difference between counties' GDP growth by industry, as well as each county's three closest neighbors in terms of distance where we have economic data. For each county affected by a legacy route closure, we found the five (or fewer, if all errors were above a predefined threshold) counties that had the lowest mean-squared-error score during the same time period from the set of counties that met the following criteria to build robust datasets and preserve the data's i.i.d. nature.

Specifically, we outlined several distinct requirements for control counties.

1. The county hadn't experienced a legacy route closure after 1990 or in the 5 years following our target county's legacy route closure.
2. The county has a direct flight to the same airport that the treated county lost a flight to.
3. The county is not in the same market as the treated county.

We used these counties as the basis of our control group to construct the model for the effect of a given route closure on our treated county.

Additionally, to create the synthetic control unit, SCMs use a weighted combination of control units' pre-intervention data, where the weights are chosen such that the synthetic control unit closely matches the pre-intervention outcome of the treated unit. In our case, to obtain the correct weights for our model to find the exact drop in GDP growth, we ran a least-squares regression on our models.

In order to ensure the highest confidence in our analysis as possible, we did not analyze legacy route closures during select time periods: 2001 to 2003, 2008 to early 2009, and anything after 2019. Major domestic and international events such as 9/11, the Global Financial Crisis, and the COVID-19 pandemic, respectively, can reasonably be expected to have influenced economic activity in cities, potentially overshadowing or even reversing changes in GDP outcomes that we might have been able to attribute as due to legacy route attrition.

It is important to note that the difference-in-differences method assumes a fixed, constant reduction, which is supported by the continued parallel trends which permeate our data. However, the standard errors are likely underestimated in most models due to significant autocorrelation between data points. A solution to correct for the standard errors which we utilized is to apply heteroskedasticity- and autocorrelation-consistent (HAC) standard errors as proposed by Newey and West (1987). HAC-robust standard errors do not change the coefficients, yet they increase the standard error.

Therefore, the synthetic control model is highly applicable to the task at hand of quantifying the loss of GDP growth as a result of legacy route closures in different environments.

We decided only to look at legacy routes because we hypothesize that non-legacy routes have not been in place long enough for economic environments to adapt and utilize the route's value in a significant way. **We confirmed this hypothesis by evaluating all non-legacy route closures: there is no consistent impact on industry GDP growth rates when non-legacy flights are eliminated.** Only at four quarters of service did we start to see consistent impacts, hence our cutoff is set at one year. We have found some common traits in the analysis, and have included examples to highlight the impact.

It is important to note that due to the availability of data on GDP growth as well as on route closures, our ability to train models was limited. Nonetheless, we validated findings up to 5 years into the future and found that route closures had noticeable effects in the data for about 3 to 4 years on average. This leads us to believe that, in the short term, small counties are forced to adapt to changing routes, but within 3 years, the new environment is adjusted to and, a small fraction of the time (< 10%), routes to larger airports return.

It is also important to recognize that the difference-in-differences model struggles with impacts that have longer time horizons, such as the labor shift from business and hospitality to manufacturing that often occurs after the elimination of a route between a large and a small county.

To maintain legibility, we plot anywhere from two to three years after route elimination.

Synthetic Control Model Results

Utilizing the above adaptations to our specific study, we constructed our SCM. A few illustrative cases and general commonalities are highlighted.

Recreation Sees Material Harm

After applying our SCM to treated counties, we found evidence to suggest that **small counties that experience route attrition see shifts away from hospitality and culture programs to traditional, high-volume and low-benefit industries.**

One can look to Amador County, California for a prime example of the impact of route attrition. With a population of 40,000, Amador is known for its high-end wineries [27]. From 2012 to 2016, as travel rates reached record highs, the county saw tourists arrive as far as Miami through American Airlines [8]. Yet, after route attrition, we hypothesized that Amador would suffer in arts, recreation, and entertainment segments as fewer tourists would be able to take direct flights to the county.

We obtained the following results using our customized SCM.

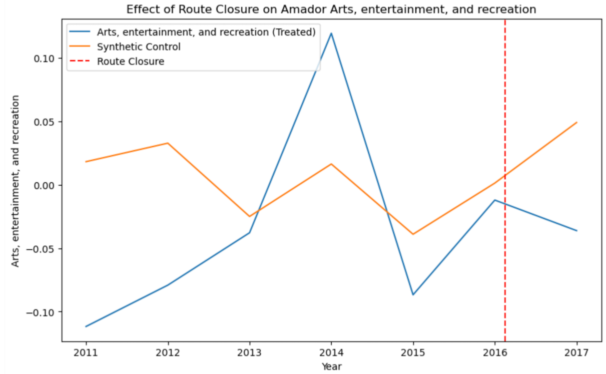

Figure 11: Amador Arts, Entertainment, and Recreation

Our model found a direct year-over-year drawdown in the county's Arts, Entertainment, and Recreation

GDP growth of 250 basis points. In other words, **Amador's entertainment sector lost about 3% of its value from 2016 to 2017.** Had American Airlines not canceled the direct flight from Miami in 2016, Amador would have lost only about 0.5% of its entertainment industry value. This means that **route elimination alone slashed nearly $75,000** in annualized entertainment GDP growth for the county.

Although the variance between the real and SCM data from Amador is noteworthy in the pre-treatment stage, the counterfactuals used in this and other statistically significant examples have GDP trends from year to year that are highly similar within each industry. Nonetheless, to create the best model possible by considering total GDP growth across all industries, we were forced to compromise some industry-to-industry variance in pre-treatment.

It is important to note that **declines in entertainment driven by the financial brunt of less air travel are coupled with a simultaneous shift toward more traditional industries such as manufacturing.** Indeed, despite variance before route elimination in the case of Amador, a notable outsized jump can be seen in manufacturing GDP post-elimination.

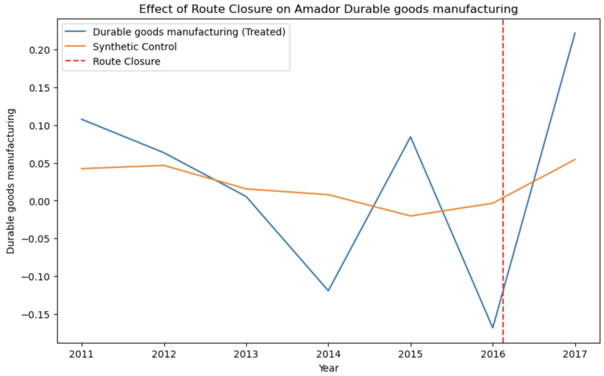

Figure 12: Amador Durable Goods Manufacturing

Impacts such as these are not limited to Amador. **Across our data, we found that the average loss in arts, entertainment, and recreation GDP growth due to one lost route is about 1%.** When considering the real effects this has on people who live in and work in counties affected by route attrition, this is not an inconsequential margin.

Flight Attrition Hits Public Utilities

While route attrition has varied effects on each industry, by and large, the most impacted sectors in statistically significant observations (defined as $p < 0.05$ in this study) are utility and utility-adjacent sectors.

Indeed, the only industry which consistently saw a change after a route elimination was utilities. **Utilities saw year-over-year GDP growth rate decline by at least 300 basis points in 15.5% of samples overall, and in 23% of samples of cities with a maximum population of 25,000.** In fact, utilities were the only industry that impacted large cities as well — in one case, when a route from Trenton, New Jersey to York, North Carolina was suspended, both saw statistically significant drawdowns in their utility GDP growth.

It is difficult to ascertain exactly why utilities are so strongly affected by route attrition. We argue that because utilities include public maintenance, in small cities where an airport can be one of the largest facilities that must be maintained, outsized impacts are more common as route attrition lessens upkeep of large, expensive equipment. Future research can capture the nuances of this further.

Large Cities Weather the Storm

We found that while small cities often see negative impacts from route attrition, larger cities tend to see little if at all. Intuitively, this makes sense: larger cities already receive more flights per day, so the loss of any one route has a comparatively smaller impact on GDP growth prospects for the city. Looking at Salt Lake City, Utah, which has a population over 200,000, route attrition plays no statistically significant role in any changes to overall nor industry-specific GDP growth year over year. Indeed, as seen below, our SCM is able to pretty accurately predict Salt Lake City's arts, entertainment, and recreation GDP growth as it is hedged against singular route elimination.

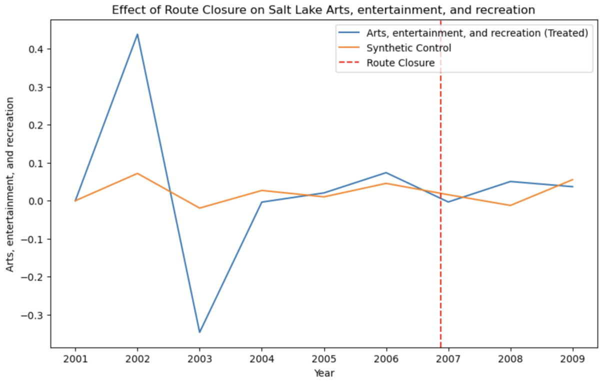

Figure 13: Salt Lake Arts, Entertainment, and Education

Consistent with our motivating anecdotal research, smaller cities often are the ones that have to face the fallout from route attrition whereas large cities are unaffected.

Key Findings

We first examined the self-perpetuating relationship between high fares and low demand in rural and small-town airports. **We provided the first quantitative evidence for this fare-demand cycle theory.** Namely, we found that canceled routes see markedly higher fares in the tail end of their service when standardized against the industry average.

Next, we built upon research by NASA's Jet Propulsion Laboratory on the effects of increasing temperatures and a less dense atmosphere in carving into conditions necessary for airplane lift. **We presented the first preliminary evidence in support of the influence this phenomenon has had on real-world route cessations.** In particular, we found that, on average, terminated routes exhibit temperatures more than two degrees Fahrenheit higher than those of non-terminated routes regardless of geography.

After, we investigated the influence of post-crisis airline media mentions on route terminations. We concluded that the process for deciding which routes to terminate does not seem to be affected by media sentiment. As such, we posit that flight terminations are principally based on profitability-centered metrics.

Lastly, we sought to corroborate aggregate observational data on the disparate impact flight closures have on rural and small towns. **Leveraging more granular methods, we found that having fewer passengers is the largest predictor for flight cancelation, with smaller airports more likely to experience closures.** Further, when these routes do terminate, we observed real economic harm for the encompassing locality.

Policy Recommendations

To address the decline in air service for rural and small towns, we present a dual approach leveraging both policy research and our statistical analyses. Principally, we suggest providing increased incentives for airline carriers to form partnerships with rural and small towns, thereby extending base coverage into these regions. Additionally, to tackle fare-demand cycles, we propose the careful expansion of federal subsidies for rural and small-town airports through the Essential Air Service program.

Future Research Directions

Throughout our investigation, we came across several promising avenues for future work.

Economics of Intermediary Cities

In this study, we analyzed the impact of the absence of air service on surrounding communities. Further work can look into the less direct diametric question of how rural and small towns are affected not by the absence of flights but by the presence of flights that travel over them. This phenomenon, known as the intermediary cities problem, has been widely documented with high-speed rail [14, 15, 16]. **We posit that a similar effect may be seen with direct flights in that the tightening of existing routes may impact the relative economic attractiveness of localities that are not part of the network.**

Impact of Mergers and Acquisitions

Vast anecdotal accounts have discussed the potential impact of airline industry conglomeration on the comprehensiveness of service offerings [17, 18, 19]. Future directions can investigate the empirical effect of mergers and acquisitions on both flight service and flight fares with respect to rural and small-town communities. **We suspect that the accelerating monopolization in the airline industry may play a part in the simultaneous decline of air service to less profitable localities.**

Transit Substitution Effect

While air service can provide unique time and convenience-based benefits, it is certainly not the only available means of transportation. Past research has examined the impact of alternative means of transportation on consumer behavior and preferences [20, 21], and future work can look into the importance of accessible substitutes for air service on local economic vitality. **We posit that the existence and recent expansion of infrastructure systems across the country may have a mitigating effect on the harms associated with temporary route closures and permanent service terminations.**

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