Abstract:

Measuring the degree of competition in markets is essential for policy and decision makers. Commonly used structural indices (e.g., HHI) overlook the way in which firms compete, and hence their prices setting in markets. We propose a new measure: the Schedule (Temporal) Differentiation Metric, STDM, which encapsulates firms’ market shares as well as the degree of overlap and substitution between their competing services. We demonstrate the STDM using aviation markets and discover a significant improvement in explaining price levels and structure. The information captured by the STDM also explains fares across fare percentiles depending on the competing airlines’ business models.

Keywords: airlines, competition, HHI, flight frequency, product differentiation

JEL Classification: L13, L93, D22
1. Introduction

Assessing the degree of competition in markets can be a key metric for decision and policy makers. Understanding the status quo between markets can lead policy makers to restructure markets, remove barriers to trade, impose restrictions on firm behavior or strategies, or seek other measures to increase supply (examples include release of spectrum to communication markets, limit the purchase to new/small firms, break apart financial institutions/telecom firms, slot controls at airports and so forth). For decision makers in private industry, a precise understanding of the degree of competition can lead to market entry/exit decisions, differentiation/assimilation strategies, as well as other capacity and service decisions.

Over the years, numerous methods have been devised to capture and measure the degree of competition and concentration in markets. Methods include simple counting of the number of competing firms, the concentration ratios CR(n) that captures the market shares of the largest n firms to assess the extent to which a given market is oligopolistic, the price-cost margin (Lerner index) measuring the mark-up in price over marginal cost, or relative profits encapsulating the change in competition. A popular measure of concentration in market structures is the Herfindahl–Hirschman Index, or HHI, which is constructed using the competing firms’ market shares, as well as the number of firms. Competition indices, such as HHI, only provide an indication of the expectation of competition, but do not provide any indication of the extent to which firms or products are rivalrous or the extent of competition in the market. For example, they generally do not differentiate between a duopoly with low prices due to intense competition and a duopoly with high prices due to lack of rivalry. Similarly, they also do not distinguish between market shares that result due to quality variations. That is, such measures ignore how firms compete with each other.

This issue has been addressed by Hausman et al. (1992, 1994), who have refined the HHI by accounting for heterogeneity of products via estimations of cross-price elasticities. They argue that while “closeness of characteristics” is difficult to measure, cross-price elasticity gives a natural measure for “closeness” for competitive purposes. The authors also admit that calculating the measure requires extensive data that often is not available (such as cost data). Our contribution

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1 As an example, the existence of regulations as well as some practical barriers in Egypt prohibit any domestic airline operating a flight within 2 hours of any EgyptAir flight especially at Cairo Airport (OECD, 2014).

2 We provide a more extensive review of the literature on measurement of competition in the next section.
addresses this point exactly: in many industries the closeness of characteristics can actually be directly measured, and market shares are easily observed. Accordingly, in this article we propose a new measure which we illustrate using the airline industry.

Our measure, Schedule (Temporal) Differentiation Metric, or STDM, captures two important dimensions of competition that are prevalent in many service industries: the frequency of service operations and the temporal differentiation between these services. To capture these dimensions, the STDM weighs the time differential between each pair of services operated by competing firms while accounting for their ordinal ranking; the nearest competing service (measured by time difference) is more substitutable than the farthest service operated by a competitor. The level of substitution between competing products is seized by the STDM. We measure the STDM at the market level which is an origin-destination airport pair.

Our measure possesses several intuitively appealing properties: it generally decreases as the competing firms increase their degree of overlap as measured by the time differential between their services, and the range of values of STDM generally decreases as firms increase their frequency of operations. It is important to note that these aspects—frequency of operations and degree of overlap—interact with each other. Specifically, when a firm increases or decreases the frequency of its operations, it also influences the degree of substitution between competing services. Thus, the change in STDM due to a change in frequency depends on the timing of the new service in the firm’s schedule or on how the firms redesigns its entire schedule. Because firms in practice seek to distribute their frequencies during the day, we observe a decrease in the value of STDM as more services are added.3

This measure is bounded from below by zero, indicating two alternative configurations: (i) a complete continuous overlap between the competing firms and (ii) a single service offering provided at the same time. The first case, which is somewhat unrealistic, reflects a situation where service is offered at any point in time by each of the competing firms. The second case is the scenario where each firm operates a single service offering and they are all scheduled to take place at the same time, a not uncommon outcome in airline markets. The upper limit of this measure is the maximum possible time difference between two competing services. For example, in a non-

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3 Although there is evidence of clustering of flights in the earlier part of the day, this observation is true at the airport level. With a single flight per day, a market is likely to be served in the morning. Once markets are served by multiple flights, clustering is no longer prevalent. For instance, in the SFO-LAX market, United Airlines and Southwest operate multiple daily flights that are almost evenly spread throughout the day.
circular 24 hour schedule, the farthest apart two services can be scheduled is 24 hours, giving rise to an STDM of 1440 (when measuring the STDM in minutes).\(^4\)

Our model is related to the product diversity and the location (or address) model literatures.\(^5\) Optimal product diversity depends on the range of tastes of consumers as well as the existence of any scale economies or fixed costs. The trade-off for the firm is determined by how much consumer surplus the firm can appropriate from greater diversity, versus the costs of both producing diversity, and any scale economies from production. Consumers can be viewed as preferring more variety to less, and that products are more substitutable the closer together they are in product space.

There is also a strategic component where firms can enter product space in different ways. They can cluster, which increases substitutability and competition, or they can differentiate, which reduces substitutability and competition, and places a product (or variety) closer to some sub-group preferences for which there may be an elastic or inelastic demand. Church and Ware (2000) discuss the conditions for insufficient vs excessive entry of products.\(^6\) Dixit (1979) for the case of oligopoly, and Spence (1976) and Dixit and Stiglitz (1977) for monopolistic competition, have shown that the market can produce greater product diversity at higher prices, or less product diversity at lower prices.

The intensity of competition will depend on whether a firm decides to add to variety, or to enter the market with a new product. Church and Ware (2000) show there is a bias against entry of new products with relatively inelastic demand and with greater fixed costs (Dixit and Stiglitz, 1977). In competitive markets increasing substitutability, being closer in features to a competitor product, increases the cross elasticity and the size of the potential surplus. However, greater competition will bid down prices as well as the surplus appropriated by the suppliers. As markets are more concentrated, there are several forces at work affecting the firm’s decision to be more, or less, rivalrous. As marginal costs increase, entry is less likely. One might argue that, as the distance

\(^4\) A non-circular schedule implies that a service on Monday is not substitutable with a service on other days. This is consistent with the assumption in the literature that travel dates are fixed (see, e.g., Armandier and Richard, 2008).

\(^5\) See Tirole (1988) or Church and Ware (2000) for a full discussion of optimal product diversity and Hotelling and Salop location models.

\(^6\) Church and Ware (2000) argue that insufficient or excessive entry of products depends on two opposing effects: business stealing and nonappropriability of total surplus. Specifically, when a new product enters the market it will steal some customers from other firms; yet, while the generated surplus exceeds the fixed cost, the latter is greater than the new profit, as some of the benefits from introduction are captured by consumers.
from an existing product increases, the marginal cost to the firm will likely increase.\(^7\) Also, less elastic demand discourages entry unless the firm with market power can increase price sufficiently to capture larger amounts of surplus. If there is a monopoly, it is likely that there will also be greater variety if there is a range of customers some with strong preferences regarding the particular variety of product. A simple address model shows that a monopolist will produce more variety, with product variety spread out in product space, as more surplus can be appropriated.

Rivalry increases as products are closer substitutes. Changes in rivalry can take place by rearranging the degree of variety, determining the closeness of substitute products, and more product entry.\(^8\) There are two effects, the demand effect and strategic effect. The demand effect incentivizes firms to increase substitution, and to increase rivalry so as to capture consumers with a preference for that variety or close to that variety. The strategic effect recognizes that, as variety or distinctiveness decreases, there is more competition and lower prices.

An index of rivalry that considers the numbers of products (firms) and the variety of products (to what extent they are different), can indicate whether prices will be high or low. Increasing variety may not lead to lower prices. Increased variety may lead to higher prices because as the market becomes more segmented, and given the fixed costs of entry, new products will have fewer buyers, but these buyers will have products that have the desired features, and the willingness to pay is higher. That is, an increase in prices occurs when goods of varying qualities in the market allow firms to extract a higher surplus from consumers. Similarly, reducing variety may lead to either higher or lower prices. Higher prices would result if the variety supplied is distinct from consumer’s desired variety and from a lack of substitutes. Lower prices could result from cost economies from producing more units of fewer products.

We demonstrate our STDM and test its efficacy in capturing the level of prices using data from the airline industry. Using data from the first quarter of 2014, we measure the frequency of operations and the time differentials between flights in several hundred U.S. domestic markets on a representative day. Limiting our attention to duopoly markets, STDM captures key aspects of competition in service markets and the relationship between these features and the realized prices.

\(^7\) In the empirical example that we use later in this article, if flights are closer together, fewer gate personnel are needed as the same teams can easily move from one flight to another. However, as flights are spread throughout the day, more teams may be necessary to maintain product quality.

\(^8\) The decision on ‘entry’ will depend on both the profitability of the product and the amount that it steals from adjacent products. A monopolist can control the amount of stealing while this is not true in oligopoly.
in those markets. Importantly, incorporating STDM improves the predictive power for the models quite significantly. Further, the STDM adds results above and beyond HHI, the traditional market competition measure.

Extended analysis of STDM also reveals different impacts at the different fare percentiles suggesting that diverse consumer segments respond differently to changes in STDM. Particularly, we find evidence that STDM is a more important factor in driving fare levels than HHI for many of the fare percentiles: fares are more responsive to the degree of overlapping schedules (STDM) than to changes in market shares (HHI). This leads us to explore more closely another strategic dimension in the structure of competition: whether the competing airlines are full service carries (network airlines) or low cost carriers (LCCs). This refinement reveals that after accounting for the type of rivalry between the two competing carriers (network vs network, LCC vs LCC, or network vs LCC), it is primarily STDM (and not HHI) that explains the fares at the different percentiles when at least one of the competitors is a network carrier. Market competition between two LCCs is primarily on price, whereas a network carrier offers connectivity and service, suggesting a higher level of importance is attributed to the schedule overlap.

The STDM developed in this manuscript can support and guide policy and decision making in the airline industry as well as other service industries. As an example, one can consider the policy imposed by the Egyptian government to limit the operations from carriers other than EgyptAir at the Cairo airport. Our STDM indicates that such a policy, which restricts the degree of overlap between schedules, and limits the frequency operated by the competitors, has the potential of increasing the premium that EgyptAir can charge its passengers.

This article is organized as follows. In Section 2 we review the literature on competition intensity measurement. Section 3 introduces our proposed measure, STDM. The data used for the application of STDM is described in Section 4. Section 5 estimates the relevance of STDM in evaluating the effect on transacted fares. Section 6 concludes.

2. Measuring Competition Intensity
2.1. General approaches to measuring competition
Firms compete in a variety of ways including pricing, quality, accessibility and networking. When firms compete, there is a resultant market structure characterized by the number of competing firms and the distribution of market shares across these firms. There have been a number of metrics
of the expected degree of competition based on the way in which the market is structured. The most popular metric is the Hirschman-Herfindahl index (HHI) which is a measure of the degree of competition based on how a market is structured. This metric is an ex post measure of firm competition. Empirical studies that use the HHI as an explanatory variable interpret its influence on a variable, price, for example, should the value of the HHI change (e.g., Gerardi and Shapiro, 2009, Borenstein and Rose, 1994, and Evans et al., 1993).

Although the HHI correctly indicates a decrease in concentration due to entry, it may not necessarily indicate the change in the actual level of competition in the market. For example, abolishment of a cartel may result in a market exit due, for example, to inefficiencies, in which case market concentration increases, while the actual level of competition intensifies. Also when efficient firms behave more aggressively, they end up with an increased market share, although this may result in a higher HHI, the actual level of competition intensifies.9 That is, the HHI is sensitive to the product and geographic market definition used, and secondly, it gives equal weight to the market share inequality and numbers of competitors (Hannan, 1997, and Lijesen, 2004).

One way of considering the intensity of competition10 is to see the extent to which products are substitutes or the degree that their characteristics overlap (Lijesen, 2004).11 Behrens and Lijesen (2015) measure the intensity of competition using conduct parameters. Their index, labelled a best-response-measure (BRM), assumes that any overlap will entice a response from the other firm; the closer substitutes, or more overlap, the greater the response.

Boone et al. (2007) have proposed a new metric of competition intensity by measuring the profit elasticity (PE), the elasticity of profit with respect to cost levels, noting that a higher PE signals more intense competition. In a related article, Boone (2008) has proposed another measure: the relative profit differences. This metric relies on the firms’ varying degrees of efficiency and how these differences translate into varying degrees of profit. A drawback of this metric is the requirement that all firms have different efficiency levels.12

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9 Only in the case of a homogeneous good and a Cournot market is the link between concentration and profitability assured (see Cowling and Waterson, 1976).
10 Rivalry refers to the actions of firms (or products), that try to take market share and profits from another firm or product. The intensity of this rivalry can refer to the amount of pressure one firm or product places on another. Fierce rivalry can lead to capturing more market share whereas less rivalry can result in simply sharing the market.
11 Lijesen (2004) tests his model on aviation data using a single quality feature, non-stop versus one-stop flights between an origin and destination.
12 These two measures are relevant for industry wide estimations.
2.2. Measuring competition in the airline industry

In competitive environments firms establish their market position through certain competitive features, such as price, differing dimensions of service or product quality, location or making a product more easily accessible, to name a few. Alternatively, firms may seek to horizontally differentiate their services and products from their competitors’, meaning they persuade people their products are different or better.\textsuperscript{13} In aviation markets firms primarily focus their competition on the prices and/or qualities of their services. Those services amount to a collection of features such as the amenities offered on board, the seating, connectivity, or the loyalty plan. One of the most important features in aviation markets, like in many other transportation markets, is the timing and frequency of the flights offered by the airline.\textsuperscript{14}

Flight frequencies and schedules play an important role in the competitive environment faced by airlines as noted in the literature. For example, Richard (2003) modeled airline rivalries in flight frequency, arguing that passengers have a desired departure time, and multiple departures allow passengers to find a more appropriate flight that reduces their inconvenience (or schedule delay);\textsuperscript{15} Ivaldi et al. (2015) described a flight accessibility variable, which is inversely proportional to an airline’s flight frequency and found that passenger demand increases by frequency. Additional support to this notion comes from Peeters et al. (2005) who found that frequency is an important consideration as high yield passengers are willing to pay for reducing the schedule delay. This may result with duopoly aviation markets exhibiting an S-curve competition (Wei and Hansen, 2005), where a high proportion of flight frequency translates into an even higher share of passenger traffic. Thus, as airlines engage in competition they end up increasing their frequencies, and as they increase their frequencies, they may use smaller aircraft. Indeed, this competition presents airlines with a trade-off: while larger aircraft offer economies of density and energy use savings (Givoni and Rietveld, 2010), they may introduce schedule delay.

Richard (2003) provides estimates of the relative importance of price and frequency in passenger’s decisions. He shows that airline consumers significantly value the convenience of a

\textsuperscript{13} Vertical differentiation is the case where market participants all agree there are clear differences between products whereas with horizontal differentiation market participants do not agree in which product are superior or preferred.

\textsuperscript{14} We recognize there are differing airline business models where low cost carriers (LCCs) focus entirely on low cost and low fares. Even within LCCs there is a degree of differentiation: some carriers offer low frequency (e.g. Ryanair) and others offer higher frequencies (e.g. Easyjet). See Klophaus et al. (2012) for the diverse business strategies among European LCCs.

\textsuperscript{15} The concept of schedule delay was introduced by Douglas and Miller (1974).
flight schedule with multiple departure times. Martin et al. (2008) estimated a stated preference model exploring passengers’ willingness-to-pay (WTP) for food, comfort, reliability, ticket flexibility and flight frequency. They found that the WTP for an additional flight was €3 for leisure passengers but €15 for business passengers.

Generally, in the literature, it has found that hub-and-spoke network carriers have higher route frequencies than point-to-point networks. Brueckner and Spiller (1994) state that the route operations of airlines hinge on density economies. Moreover, Wei and Hansen (2006) show that airlines can attract more connecting passengers in a hub-and-spoke structure by increasing service frequency than by increasing aircraft size. An additional factor affecting flight frequency is the nature of the contract between network carriers and regional airlines. Forbes and Lederman (2009) find that major carriers that own, rather than contract out for regional airline feed services, have a superior ability to control flight schedules. They, like Gillen et al. (2015), find regional carrier ownership results in increased frequency and the use of smaller aircraft.

The competition measure we propose in the next section accounts not only for the frequency of flights operated by a carrier, but also for the degree of overlap with competing carriers operating the same route.

3. **The Frequency - Schedule (Temporal) Differentiation Metric**

Our measure captures the two important features discussed in the literature: (i) the schedule differentiation between competing airlines; this can be perceived as the degree of overlap of the competing firms’ schedules and, (ii) the daily frequency of operations. Such features would not be captured by using simple time differences between flights; the average time difference between flights does not incorporate the level of substitution between flights. Similarly, measuring only the time difference between the closest flights does not take into account the concentration in the market. These aspects relate to the capacity-frequency trade-off that airlines face in competitive markets—increasing frequency may force airlines to switch to smaller aircraft. Yet, at the same time, increasing the frequency of operations may also allow airlines to increase their fares.

Capturing both features in a single measure creates a challenge in maintaining monotonicity: as airlines increase their frequencies, they increase their own temporal differentiation and possibly the degree of overlap between their schedules, and as airlines change the timing of their flights, they change the way that their flights overlap, and the way that they compete with each other, without affecting the frequency of flights.
At the extreme case—the lower limit—each airline offers a single daily flight and these two flights depart at exactly the same time. We assign a value of zero to this scenario, reflecting the complete overlap between the two competing carriers. As the two carriers start differentiating the overlap between these two flights, the measure simply captures the time differential between the flights.\(^\text{16}\) In principle, the other extreme case—the upper limit—is where airlines offer two flights, one each, at the farthest time differential form each other. Considering a 24 hour schedule this gives rise to a difference of 1440 minutes. This is the maximum value that the STDM can reach. As airlines increase their frequency, one can consider the hypothetical case of airlines offering flights on a continuous basis.\(^\text{17}\) Of course, in cases of slot-constrained airports, such as Heathrow (LHR), Mexico City, LaGuardia or JFK (New York), frequency is often determined by total slots available. More realistically, we expect to observe that airlines that are engaged in intense competition will possibly offer somewhat similar schedules to win over the customers in these markets, or airlines that bracket each other’s flights such that their schedules are spaced out during the day.

To facilitate the metric we account for each airline’s schedules of flights and the way in which each flight competes with the other airline’s flights. We assume that flights that are temporally closer to each other are closer substitutes and hence compete more fiercely, whereas flights at the opposing end of the daily schedules are weaker substitutes. To account for this temporal competition and substitution we allocate more weight to competing flights that are closer in the schedules. To construct our measure, Schedule (Temporal) Differentiation Metric, or STDM, we require the schedule ranking between each pair of flights operated by competing carriers as well as the time differential between them.

We use matrix notation to construct the STDM and we demonstrate using the case of duopoly, although the concept can be generalized to more competing firms. We assume there are two carriers—Airline \(i\) and Airline \(j\)—competing in a market, with Airline \(i\) operating \(N\) flights and Airline \(j\) operating \(M\) flights. We introduce the following notation. Let \(F_{i,n}\) denote the \(n^{th}\) flight of Airline \(i\), and similarly let \(F_{j,m}\) denote the \(m^{th}\) flight of Airline \(j\).

We let \(D_{m,n}\) denote the absolute time difference between the scheduled departure times

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\(^{16}\) In that respect another consideration emerges: are flights offered on different days substitutable or not? We assume that passengers demand flights for a particular day of travel and hence we limit our attention to intraday flight substitution.

\(^{17}\) In our data the maximum number of flights operated in a market is 25 in a single day.
of flights $m$ and $n$, $F_{i,n}$ and $F_{j,m}$, which are operated by competing airlines $i$ and $j$. These time differences between every pair of competing flights are stored in the $M$ by $N$ matrix $\text{DIFF}$, to allocate different weights to competing flights based on their adjacency. We next capture the ranking of flights with respect to each other; we first rank the flights of Airline $j$ with respect to the flights of Airline $i$. These rankings are stored in the $M$ by $N$ matrix $\text{RANKN}$; this matrix denotes the inverse ranking of the scheduled departure of $F_{j,m}$ with respect to the scheduled departure of $F_{i,n}$. Thus, each column in $\text{RANKN}$ will have the entries $1, \frac{1}{2}, \ldots, \frac{1}{M}$ sorted according to the sequence described. We then rank the flights of Airline $i$ with respect to the flights of Airline $j$. These rankings are stored in the $M$ by $N$ matrix $\text{RANKM}$ where $\text{RankM}_{m,n}$ denotes the inverse ranking of the scheduled departure of $F_{i,n}$ with respect to the scheduled departure of $F_{j,m}$. Thus, each row in $\text{RANKM}$ will have the entries $1, \frac{1}{2}, \ldots, \frac{1}{N}$ according to their relative ranking.

The three matrices defined above are multiplied to yield the, STDM matrix, $\text{STDMM}$:

$$\text{STDMM} = \text{RANKN} \cdot \text{DIFF}' \cdot \text{RANKM}.$$ 

Finally, STDM is calculated by aggregating over the cells of $\text{STDMM}$ and normalize by the scale of operations (i.e., dividing by the product of the squared number of flights):

$$\text{STDM} = \frac{\sum_{n=1}^{N} \sum_{m=1}^{M} \text{STDMM}_{n,m}}{N^2 M^2}.$$ 

For simplicity we calculate this index in minutes, although it can easily be quantified in any other time units. This measure, STDM, is effective in capturing the dimensions of competition that arise when firms operate substitutable schedules. We will demonstrate the different values that can be generated, and in subsequent sections, illustrate the strength of STDM in explaining realized prices in markets.

**Example.** Consider a market served by two airlines, Airline 1 and Airline 2, each offering two daily flights. Airline 1 operates flights at 8am and at 2pm, whereas Airline 2 operates flights at 11am and at 5pm. These flights are illustrated in Figure 1, Airline 1 is denoted by a dark circle and Airline 2 by a hollow circle.
The Diff matrix is derived by calculating the time differential (in minutes) between every pair of flights operated by the two airlines. The entries in the first column in the matrix are the times between Airline 1’s first flight (at 8am) to Airline 2’s flights (at 11am and at 5pm); 180 minutes and 540 minutes, respectively. The entries in the second column are the times between Airline 1’s second flight (at 2pm) to Airline 2’s flights (at 11am and at 5pm): 180 minutes in both cases. Hence,

$$\text{Diff} = \begin{bmatrix} 180 & 180 \\ 540 & 180 \end{bmatrix}.$$ 

To find the entries in the first column of the RankN matrix note that Airline 2’s first flight (at 11am) is the nearest to Airline 1’s 8 am flight, hence $\text{RankN}_{1,1} = 1$, and Airline 2’s second flight (at 5pm) is the second nearest and hence $\text{RankN}_{2,1} = \frac{1}{2}$. To calculate the entries of the second column of RankN, note that Airline 2’s flights are of equal distance from Airline 1’s second flight (at 2pm). We break ties by using the ordinal ranking, so the 11am flight is the “nearest” being assigned a value of 1 and the 5 pm flight is assigned a value of $\frac{1}{2}$. Thus, RankN is given by

$$\text{RankN} = \begin{bmatrix} 1 & 1 \\ 0.5 & 0.5 \end{bmatrix}.$$ 

RankM is calculated in a similar way. To find the entries in the first row—the ranking of Airline 1’s flights with respect to Airline 2’s first flight (at 11am)—we note that both flights are of equal distance. Since the 8am is the first flight, it is assigned a value of 1 whereas the 2pm is assigned a value of $\frac{1}{2}$. The second row captures the ranking of Airline 1’s flights with respect to Airline 2’s second flight (at 5pm): since Airline 1’s second flight (at 2pm) is the nearest, $\text{RankM}_{2,2} = 1$, while Airline 1’s first flight (at 11am) is the second nearest, $\text{RankM}_{2,1} = \frac{1}{2}$. Accordingly, RankM is

![Figure 1. Example of flight schedules by two competing airlines (Airline 1 in black, Airline 2 in white)](image-url)
\[ \text{Rank}M = \begin{bmatrix} 1 & 0.5 \\ 0.5 & 1 \end{bmatrix}. \]

Multiplying the three matrices, we have:

\[ \text{STDMM} = \text{Rank}N \cdot \text{Diff'} \cdot \text{Rank}M = \begin{bmatrix} 720 & 900 \\ 360 & 450 \end{bmatrix}. \]

We normalize by dividing by the product of the squared number of flights operated by each of the airlines:

\[ \text{STD} = \frac{2430}{2^2 \cdot 2^2} = 607.5. \]

We now proceed to describe and demonstrate several characteristics of the STDM.

**Property 1 [Two Flights]:** With two competing flights, STDM equals the time difference between these flights.

To demonstrate this property, consider the case when each airline operates only one flight, \( N=M=1 \). Then, \( \text{Rank}N \) and \( \text{Rank}M \) are 1x1 matrices with this entry being equal to 1 in both cases, and \( \text{Diff} \) is also a 1x1 matrix. Hence, STDM equals the entry of \( \text{Diff} \), which is the time difference between the two flights.

This property, although for two flights, is a characteristic of the general behavior of STDM that, as flights are farther apart from each other, the value of STDM increases. This is the primary feature of STDM in capturing horizontal differentiation between competing firms in a market.

**Property 2 [Symmetric Maximum Differentiation]:** Assume \( M = N \). STDM decreases in \( M \). That is, STDM decreases as both carriers increase their frequencies while keeping maximum differentiation.

To see this property, let \( t \) denote the maximum differentiation between two flights. This can be determined by the time difference between the first and last slots of the day. Now assume that as carriers increase their frequencies, they locate the new flights to overlap with their existing flights. Thus, all flights for both carriers are concentrated at (about) the same time slot,
respectively. In this setting \( \text{Rank}N = \begin{bmatrix} 1 & \cdots & 1 \\ \frac{1}{2} & \cdots & \frac{1}{2} \\ \vdots & \cdots & \vdots \\ \frac{1}{M} & \cdots & \frac{1}{M} \end{bmatrix} \), \( \text{Rank}M = \begin{bmatrix} 1 & \cdots & 1 \\ \frac{1}{N} & \cdots & \frac{1}{N} \\ \vdots & \cdots & \vdots \\ \frac{1}{M} & \cdots & \frac{1}{M} \end{bmatrix} \), \( \text{Diff}_{m,n} = nt, \forall m, n. \) Therefore, \( \text{STDMM} = \text{Rank}N \cdot \text{Diff}' \cdot \text{Rank}M = \begin{bmatrix} \frac{M^2t}{M} & \frac{M^2t}{M-1} & \cdots & \frac{M^2t}{t} \\ \frac{M^2t}{2M} & \frac{M^2t}{2(M-1)} & \cdots & \frac{1}{2} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{M^2t}{MM} & \frac{M^2t}{M(M-1)} & \cdots & \frac{M^2t}{t} \end{bmatrix}. \)

We have that \( \sum_{n=1}^{N} \sum_{m=1}^{M} \text{STDMM}_{n,m} = \sum_{n=1}^{N} \sum_{m=1}^{M} \frac{M^2t}{nm} = M^2t(\Psi(M+1) + \gamma)^2 \), where \( \Psi(x) \) is the digamma function and \( \gamma \) is Euler’s constant, we have that \( \text{STD}M = \frac{M^2t(\Psi(M+1)+\gamma)^2}{M^2M^2} = \frac{t(\Psi(M+1)+\gamma)^2}{M^2}. \) We note that \( \frac{(\Psi(M+1)+\gamma)^2}{M^2} \) is decreasing in \( M \) as can be observed from Figure 2. Hence, STDMM decreases in \( M \) for any given \( t \).

![Figure 2. Demonstrating Property 2](image)

This property of the STDMM is an upper bound on the manner in which firms differentiate themselves from each other while increasing the number of flights they operate. Thus, as the number of flights increases, the range of values of STDMM (which varies between zero and this
upper bound) decreases as well. This effect of decreasing STDM despite the fixed differentiation between the flights is due to the increased number of flights offered by the competing carrier. To reiterate, our metric captures not only the differentiation between schedules but also the frequencies offered by the competing firms.

The case described in the property is hypothetical, as airlines do not usually offer all flights at exactly the same time (in which case they might prefer to switch to a larger aircraft thereby decreasing frequency) as they also seek to disperse their flights throughout the day. Thus, in more realistic situations, as airlines increase their frequencies, the STDM is expected to decrease as well, not only due to the increased number of flights but also due to the increased overlap of their schedules.

**Property 3 [Internal Substitution—Two flights]:** When one of the carriers operates two flights and the other carrier operates a flight between these two, then changing the flight’s timing within this interval does not change the value of STDM.

We demonstrate this property using the benchmark scenario illustrated in Figure 1. Now assume that Airline 1 considers rescheduling its 2pm flight. As long as the ordering of the flights does not change, we can see how the value of STDM does not change. $\text{RankN}$ and $\text{RankM}$ are as before, and only the time difference between the flights change, $\text{Diff} = \begin{bmatrix} 180 \\ 540 \\ 360 - x \end{bmatrix}$, where $x$ is the time difference between Airline 1’s second flight and Airline’s 2 flight at 11am, implying that the time difference to Airline’s 2 5pm flight is $360 - x$. Multiplying the matrices, we have

$$\text{STDM}_{M} = \begin{bmatrix} 630 + \frac{x}{2} \\ 315 + \frac{x}{4} \end{bmatrix} \begin{bmatrix} 630 - \frac{x}{2} \\ 495 - \frac{x}{4} \end{bmatrix},$$

resulting with $\text{STDM} = \frac{2430}{2^2} = 607.5$.

**Property 4 [Converging Schedules]:** When one of the carriers operates $N$ flights equally spread out, separated $t$ time units apart from each other, and the other carrier operates $N-1$ flights with each located in the middle of two flights of its competitor, the degree of competition increases as $t$ decreases.

This property of STDM can be illustrated in the following way. Given the structure of the schedules of the two carriers, the matrices $\text{RankN}$ and $\text{RankM}$, which are $N-1$ by $N$ matrices, do

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18 For example, in February 2016 Emirates has purchased a sixth slot at Heathrow airport for a flight leaving Dubai at 11:30am. This “flight can accommodate some connections that cannot make the 09:40 departure. The 11:30 service can be offered at a discount to incentivise flexible passengers to take a longer layover, thereby freeing up seats on the more prime 09:40 departure” (CAPA 2016).
not change with t as the relative ranking of the flights is fixed. Only the matrix DIFF, which is also an N-1 by N matrix, changes with t. Specifically, the entries in the matrix decrease as t decreases. Hence, the STDM value decreases as t decreases.

Using the example discussed in the benchmark case, we illustrate the above properties of the STDM and other features of this metric, using the different configurations depicted in Table 1. We first look at horizontal differentiation as one firm changes the schedule of one of its flights only. In particular, we assume that Airline 1 changes the schedule of its second flight (at 2pm in the benchmark case). First, as it shifts its timing, the value of STDM does not change (Configuration 2). This is due to Property 3. Further change in the timing of the second flight (Configuration 3) results with an increase of the STDM as the differentiation between this flight and Airline 2’s flight increases.

Contrasting Configuration 3 with Configuration 4 reveals the power of schedule separation. Namely, the degree of overlap is reduced as the two competing carriers split the operations of flights during the day with Airline 1 serving the first two flights of the day and Airline 2 serving the last two flights. This reveals that with schedule separation the value of STDM is the same as in Configuration 3 although the spread of the flights during the day is far more compact.

Configurations 5-7 demonstrate two aspects. First, as the time differential between flights decreases, so does the value of STDM. This is a main feature of the STDM in capturing the degree of overlap. The second aspect is that increasing the number of flights does not necessarily result in a decreased STDM. This is due to the reorganization of the schedule during the day. While in Configuration 6 the two flights are offered at exactly the same time, in Configurations 5 and 6, where the STDM is larger than that in Configuration 6, the increased differentiation between the flights exceeds the effect of increased frequency. Configuration 5 also demonstrates the increased substitution with respect to Configurations 1-3, which results in a lower STDM value.
Table 1. The STDM measure in different configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>STDM</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>607.5</td>
<td>“Benchmark” discussed in the Example</td>
</tr>
<tr>
<td>2.</td>
<td>607.5</td>
<td>Same STDM as in (1): the increased substitution (the overlap at 5pm) is compensated by the reduced substitution for the 11am.</td>
</tr>
<tr>
<td>3.</td>
<td>810</td>
<td>STDM increases w.r.t. to (1) and (2): Airline 1’s second fight differentiates away from Airline 2’s flights.</td>
</tr>
<tr>
<td>4.</td>
<td>810</td>
<td>Higher STDM due to “separation” of schedules. Note it is same STDM as in Constellation 3.</td>
</tr>
<tr>
<td>5.</td>
<td>405</td>
<td>STDM decreases w.r.t. (1-3): increased substitution.</td>
</tr>
<tr>
<td>6.</td>
<td>270</td>
<td>STDM decreases w.r.t. (5) as substitution increases further</td>
</tr>
<tr>
<td>7.</td>
<td>0</td>
<td>Complete overlap with a single flight</td>
</tr>
</tbody>
</table>

It is important to highlight that STDM is quite distinct from the HHI metric. The HHI which is traditionally used in [transportation] markets to capture the expected degree of competition, is a measure of market concentration based on market shares offered (e.g., how many flights) or captured (e.g., number of seats sold) by the competing firms. By contrast, STDM captures the way in which the firms compete with each other in those markets. Thus, these two measures could be perceived as complementary measures as we demonstrate in the subsequent sections below.

4. Data

After establishing the STDM and some of its properties, we will demonstrate its importance in explaining fare levels in the U.S. domestic airline industry. Our reference time frame is the first quarter of 2014. This is a time period where the industry has been experiencing a positive growth in terms of traffic, expansion of destinations, and overall the economy was growing.
4.1. STDM and HHI

To measure the STDM, we have gathered schedule information from the U.S. Department of Transportation’s (DOT) On Time Performance dataset. This dataset assembles detailed information at the flight level. While schedules may change from one day to another, the core schedule of airlines does not change dramatically during the week. Hence, in order to simplify the construction of the STDM, we decided to pick one day of the week—Wednesday—as a representative of the weekly schedule. One advantage of focusing on a single day of operations rather than the entire week of flights, is that it allows us to abstract away from the nightly gaps in operations and focus on intraday substitution between competing flights.\(^{19}\)

Similar to Brueckner and Luo (2014), we limit our attention to duopoly markets. Since some duopoly markets are occasionally serviced by other carriers, we clean the data in the following manner. We consider a market to be a duopoly if (i) the combined number of flights operated by the two competing carriers exceeds 80% of the total number of flights in the market; (ii) the third airline operates less than 10% of the flights in the market; and (iii) the second airline operates significantly more flights than the third airline; the share of flights operated by the second airline exceeds that of the third airline by at least 10%. Those restrictions guarantee that the market is dominated by two airlines and that other smaller players are indeed of a minor scale compared with the two major players in the market, effectively a duopoly market.\(^{20}\) Additionally, we apply a similar cleaning logic to markets operated by two carriers only: we remove markets where the smaller carrier’s market share is less than 10 percent.\(^{21}\) This elimination results with a final data set of 642 markets which we perceive as duopoly markets.

The distribution of the STDM measure is illustrated in Figure 3. The histogram shows the majority of the markets have an STDM of up to about 200. This suggests that in a large number of markets the schedules of the competing carriers have a significant degree of overlap. Low values of STDM could occur both in markets with low frequencies as well as in markets with higher frequencies. When a small number of flights are operated, a low STDM implies that they are closely scheduled to each other. When a large number of flights are operated, then the airlines

\(^{19}\) As mentioned before, it is common to assume that travel dates are fixed (see, e.g., Armantier and Richard, 2008).

\(^{20}\) Our cleaning is more restrictive than the method in Brueckner and Luo (2014), who simply removed all airlines with less than 20 monthly departures. While this might be an effective measure in thick markets, we believe that it may overlook some of the competition in thinner markets.

\(^{21}\) We have only 10 such markets in our data and the inclusion of these markets in our empirical analysis does not impact the qualitative results of our analysis.
might be spreading their flights throughout the day, ending up with schedules that are close to each other. At the lower end of the distribution of STDM we find a small number of markets with competing schedules that are (almost) completely overlapping. Note also that there are a considerable number of markets with STDM in excess of 200 indicating markets where airlines manage to considerably differentiate their schedules. We hypothesize that in those markets airlines will be able to extract a premium from their passengers due to the increased differentiation.

![Figure 3. A histogram of the STDM](image)

One of the characteristics of STDM, as we discussed, is that it captures both the frequency of operations as well as the substitution between competing flights. We demonstrate the former aspect in Figure 4. Specifically, this figure depicts the STDM against the total number of flights in the market; the minimum value of daily flights in our dataset is 2—one for each competing airline—and the thickest market in our dataset has 25 daily flights. As can be observed from Figure 4, the range of values of STDM is generally decreasing as the number of flights increases, as the upper bound on STDM decreases in the total frequency. This is in accordance with Property 2. With more flights, the degree of overlap between the daily schedules offered by the competing airlines increases as they generally distribute their flights throughout the day. Even if they manage
to keep their flights farthest apart from each other (Property 2), the STDM still decreases due to the increased number of competing alternatives. As the magnitude of operations increases, the amount of variation in STDM diminishes; with a single daily flight, the carriers can position their flights at the same time slot to directly compete with each other (in which case STDM can be as low as 0) or can maximize the time differential with a morning flight vs a night flight (in which case STDM can easily exceed a value of 600). With a larger number of flights during the day, as airlines start spreading their flights over the day to account for scheduling and operational considerations, the range of alternative schedules diminishes.\textsuperscript{22}

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\textsuperscript{22} We shall note that our STDM performs better than simply accounting for total frequency.
representative day of flight. We recognize that flight schedules might change (slightly) based on
day of the week and possibly during the quarter, thus a quarterly based HHI will more closely
reflect the rivalry between airlines and hence it will consistent with the observed transacted fares.
Note, even though HHI is derived in a manner closely aligned with observed fares, and STDM is
based on a single representative day, we will show that STDM has greater power in explaining
fares. Thus, reconstructing the STDM based on the entire quarter’s schedule data (which is a rather
challenging endeavour) could possibly yield an even more precise STDM with improved power in
explaining fares.

Figure 5 depicts the degree of competition as captured via the HHI measure versus the
STDM measure. This figure does not reveal any strong relationship between the two measures (the
correlation between these two measures is -0.077). There are several features worth noticing in
this figure. Due to our data cleaning criteria, the maximum HHI is 0.82 (this is when one carrier
operates 90% of the flights and the other serves the remaining 10%), while the minimum HHI
value is about 0.34. Lower HHI values can emerge when the two carriers account for 80% of flights
and the remaining are served by several marginal players. The observations along the horizontal
line where HHI=0.5 reflect markets where two airlines operate the same number of flights in the
market. However, despite the concentration of observations with values of HHI equals to 0.5, we
witness a wide distribution of the STDM. While HHI captures one dimension of the expected
competition between firms, STDM captures important elements in the way the firms compete with
each other. Indeed, while the two airlines might be offering the same number of flights, their
schedules and their degree of overlap can differ substantially from one market to another.
4.2. Dependent and control variables

Our interest is in revealing the importance of the STDM in capturing the fares in the various markets. To that end we have aggregated data from the U.S. Department of Transportation’s DB1B dataset which is a sample of 10% all airfares. Using this data, we generate a mean fare and the fares at different percentiles.

We define a market as the origin-destination pair. Economic market characteristics, measured by population and income per capita, are defined as the average across the metropolitan areas at the origin airport and the destination airport. The data from the U.S. Bureau of Economic Analysis (BEA) are used to derive the variables AvgPop and AvgIncCap, the arithmetic means of the population and the average income per capita, respectively, of the origin and destination metropolitan areas. We assemble complementary data on the distance between the origin and destination airports (available in the USDOT datasets).

23 We have also generated the Gini to capture the dispersion of transacted fares; however, our empirical analysis reveals that while the STDM captures price levels very well, it does not capture all elements of fare distribution (see the Appendix for corresponding estimations).
We also account for the type of markets. Following Gerardi and Shapiro (2009) we define two additional variables: Leisure and BusinessMarket. The former is a dummy variable that takes a value of 1 when either the origin or the destination airports serve a leisure destination. To classify leisure destinations, Gerardi and Shapiro calculated the ratio of the accommodation earnings to the total nonfarm earnings of the metropolitan area served by the airport. If the ratio exceeds a threshold of 0.85, the airport (or the metropolitan area) is considered a leisure destination. BusinessMarket is also a dummy variable and corresponds to the notion of big-city routes, this variable takes a value of 1 if both origin and destination airports are among the largest 30 metropolitan areas.

To complement these measures of competition, we have further accounted for the unique characteristics of low cost carriers (LCCs) in two ways, by accounting for their flights market share and using a dummy to indicate their presence in the market (dummy equals 1 if one of the duopoly carriers is an LCC and 0 otherwise). The following airlines were coded as LCCs: AirTran Airways, Allegiant Air, Frontier, JetBlue Airways, Southwest Airlines, Spirit Airlines, Sun Country Airlines, USA3000 Airlines, and Virgin America.

Lastly, we also account for the presence of a hub at either the origin or the destination airports. Hub airports are the focal point of hub and spoke carriers as they amass a large number of flights at the hub airport, while moving a large number of passengers. Hub airport operations can benefit airlines as they optimize their movements and take advantage of the economies of density. Additionally, while airlines might be able to charge a premium for accessing their hub, they can better negotiate with the airport operator to receive a discount for their airport charges. Hence, we capture this feature via the dummy HUBFSC that takes a value of 1 when either the origin or destination airport is a hub of one of the full service carriers (FSC) and a value of 0 otherwise.

Summary statistics of the variables used in the empirical analysis are provided in Table 2.
5. Empirical Approach and Identification

The goal of our empirical analysis is to investigate how the degree of competition affects the price levels in a given market while controlling for several variables described in Section 4.2.

5.1. Model Specification

The estimation equations are reduced-form specifications. Letting $i$ denote the market, we estimate the effect of the competition measure, STDM, via the following log-log equation:

$$
\ln(\text{Fare}_i) = \alpha_0 + \alpha_1 \ln(\text{Distance}_i) + \alpha_2 \ln(\text{AvgPop}_i) + \alpha_3 \ln(\text{AvgIncCap}_i) + \alpha_4 (\text{Leisure}_i) + \alpha_5 (\text{BusinessMarket}_i) + \alpha_6 (\text{HubFSC}_i) + \alpha_7 (\text{LCCDummy}_i) + \alpha_8 \ln(\text{HHI}_i) + \alpha_9 \ln(\text{STDM}_i) + \gamma_i + \epsilon_i
$$

where $\text{Fare}_i$ is the average fare paid for a ticket in market $i$ during the first quarter of 2013. $\gamma_i$ is the market fixed effects. The $\text{LCCDummy}_i$ variable can capture an important feature of the presence of low cost carriers; a decrease in the transacted fare could be stimulated merely due to the presence of a low cost carrier in the market, regardless of the number of flights such a carrier operates or the distribution of the flights operated by the carrier throughout the day.

5.2. Identification

The econometric problem that we are concerned with is the potential endogeneity of HHI and STDM because both are functions of the carriers’ frequencies and since the market performance feeds back to market structure (Evans et al., 1993). The classical solution is to estimate the model
by using instruments which are orthogonal to the unobservable of the equation. Specifically, we instrument the HHI with the total number of flights operated from the origin airport in the other markets (e.g. to the other destinations) and the total number of flights operated from the destination airport in the other markets. These origin and destination airport related variables cannot be adjusted in the short run, thus are uncorrelated with the contemporaneous shocks to the average fare paid for a ticket in a market. Additionally, these two variables provide information about the capacity of airports, which are predetermined, predict well the market shares while being independent of the price shocks. We address the possible endogeneity of STDM by route mean of exogenous variables such as population used in Borenstein and Rose (1994), and the total number enplaned passengers on the route following Gerardi and Shapiro (2009). We estimate the specified model by Two Stages Least Squares.

6. Empirical Results

We undertake an empirical analysis in order to understand the impact of STDM on the average fare as well as on the various percentiles (Section 6.1). We are particularly interested in discovering the relative contributions of STDM and HHI in explaining fare levels. We then refine the analysis to gain deeper understanding of the relevance of STDM by distinguishing competition between airlines with different business models (Section 6.2).

6.1. Impact of STDM

Table 3 summarizes the estimation results. Estimations 1-2 are based on the ordinary least squares method, OLS, whereas Estimations 4-6 employ the two stage least squares method, 2SLS. We generally observe that the traditional variables behave as expected. Namely, the average fare increases with the distance flown. The fare is higher when the market is coded as a business market, but lower when it is a leisure market. Intuitively, in the presence of a low cost carrier in the market, the average price is lower. Market structure effects, as measured by the HHI, reveal that as concentration in the market increases, the average transacted fare increases as well.

The average population and average income per capita variables capture potential demand. Higher incomes and higher populations may affect fares by indicating more business passengers and an increased propensity to travel. As observed in Table 3, however, these two variables are insignificant in all estimations except for the 2SLS(2) where the coefficient of average population indicates a positive relationship.
The STDM captures both frequency of operations and the substitution between competing flights. Recall that a decrease in STDM indicates an increased overlap in the schedule of the competing carriers in a market. This can occur when airlines increase their frequencies and/or schedule flights closer together. Thus, one expects an increase in the value of STDM to correspond to an increase in the average transacted fare as the supply of flights into the market diminishes and/or the flights become weaker substitutes. Indeed, the results in Table 3 show exactly that: STDM is significant in capturing the effects on prices. This is an important result. Our measure, STDM, captures crucial aspects of competition in service markets and the service markets relationship to the realized prices in those markets. Furthermore, the significance of STDM could suggest that although passengers may be willing to pay more for greater flight frequency, carriers need to weigh carefully the added benefit of reduced time schedule delay to consumers as this could be shadowed by losses due to increased substitution with competing flights.

Not only is our STDM measure significant, it also increases the predictive power of the empirical model significantly. Considering the adjusted $R^2$ of the various models, this value improves from 3 to 8% once STDM is included in the model (we note that in the 2SLS estimations our calculations of the $R^2$ based on Pesaran and Smith, 1994). STDM adds explanatory power to the level of fares above and beyond the traditional competitive measure, HHI, and the coefficient of HHI does not change in any significant way when STDM is added to the estimation. This indicates that new information is being added regarding competition and its impact on fares.
<table>
<thead>
<tr>
<th>Variable</th>
<th>OLS(1)</th>
<th>OLS(2)</th>
<th>OLS(3)</th>
<th>2SLS(1)</th>
<th>2SLS(2)</th>
<th>2SLS(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (M)</td>
<td>0.172**</td>
<td>0.164**</td>
<td>0.167**</td>
<td>0.194**</td>
<td>0.152**</td>
<td>0.213**</td>
</tr>
<tr>
<td></td>
<td>(0.0103)</td>
<td>(0.0100)</td>
<td>(0.00996)</td>
<td>(0.0168)</td>
<td>(0.0129)</td>
<td>(0.0307)</td>
</tr>
<tr>
<td>AvgPop (M)</td>
<td>-0.0193</td>
<td>0.0143</td>
<td>0.0143</td>
<td>-0.0207</td>
<td>0.109**</td>
<td>0.0757+</td>
</tr>
<tr>
<td></td>
<td>(0.0150)</td>
<td>(0.0153)</td>
<td>(0.0151)</td>
<td>(0.0213)</td>
<td>(0.0238)</td>
<td>(0.0452)</td>
</tr>
<tr>
<td>AvgIncCap (M)</td>
<td>-0.0414</td>
<td>-0.0396</td>
<td>-0.0590</td>
<td>-0.189</td>
<td>-0.0874</td>
<td>-0.446+</td>
</tr>
<tr>
<td></td>
<td>(0.0800)</td>
<td>(0.0774)</td>
<td>(0.0769)</td>
<td>(0.125)</td>
<td>(0.0993)</td>
<td>(0.235)</td>
</tr>
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<td>Leisure</td>
<td>-0.0721**</td>
<td>-0.0576*</td>
<td>-0.0580*</td>
<td>-0.0757*</td>
<td>-0.0180</td>
<td>-0.0395</td>
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<tr>
<td></td>
<td>(0.0250)</td>
<td>(0.0243)</td>
<td>(0.0240)</td>
<td>(0.0353)</td>
<td>(0.0316)</td>
<td>(0.0666)</td>
</tr>
<tr>
<td>BusinessMarket</td>
<td>0.0336+</td>
<td>0.0475*</td>
<td>0.0532**</td>
<td>0.0755*</td>
<td>0.102**</td>
<td>0.191**</td>
</tr>
<tr>
<td></td>
<td>(0.0195)</td>
<td>(0.0190)</td>
<td>(0.0189)</td>
<td>(0.0316)</td>
<td>(0.0255)</td>
<td>(0.0621)</td>
</tr>
<tr>
<td>HubFSC</td>
<td>0.0403</td>
<td>0.0351</td>
<td>0.0310</td>
<td>0.00951</td>
<td>0.00940</td>
<td>-0.0606</td>
</tr>
<tr>
<td></td>
<td>(0.0273)</td>
<td>(0.0265)</td>
<td>(0.0263)</td>
<td>(0.0403)</td>
<td>(0.0341)</td>
<td>(0.0759)</td>
</tr>
<tr>
<td>LccDummy</td>
<td>-0.348**</td>
<td>-0.324**</td>
<td>-0.324**</td>
<td>-0.349**</td>
<td>-0.256**</td>
<td>-0.280**</td>
</tr>
<tr>
<td></td>
<td>(0.0163)</td>
<td>(0.0161)</td>
<td>(0.0160)</td>
<td>(0.0230)</td>
<td>(0.0228)</td>
<td>(0.0457)</td>
</tr>
<tr>
<td>HHI</td>
<td>0.158**</td>
<td>0.163**</td>
<td>1.404**</td>
<td>3.155**</td>
<td>3.155**</td>
<td>3.155**</td>
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<tr>
<td></td>
<td>(0.0489)</td>
<td>(0.0469)</td>
<td>(0.463)</td>
<td>(0.824)</td>
<td>(0.824)</td>
<td>(0.824)</td>
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<td>STDM</td>
<td>0.0789**</td>
<td>0.0794**</td>
<td>0.302**</td>
<td>0.233**</td>
<td>0.233**</td>
<td>0.233**</td>
</tr>
<tr>
<td></td>
<td>(0.0109)</td>
<td>(0.0108)</td>
<td>(0.0348)</td>
<td>(0.0518)</td>
<td>(0.0518)</td>
<td>(0.0518)</td>
</tr>
<tr>
<td>constant</td>
<td>4.683**</td>
<td>3.738**</td>
<td>4.010**</td>
<td>6.804**</td>
<td>1.825+</td>
<td>7.786**</td>
</tr>
<tr>
<td></td>
<td>(0.805)</td>
<td>(0.781)</td>
<td>(0.779)</td>
<td>(1.379)</td>
<td>(1.037)</td>
<td>(2.476)</td>
</tr>
<tr>
<td>N</td>
<td>642</td>
<td>642</td>
<td>642</td>
<td>642</td>
<td>642</td>
<td>642</td>
</tr>
<tr>
<td>R-sq</td>
<td>0.524</td>
<td>0.553</td>
<td>0.562</td>
<td>0.530</td>
<td>0.603</td>
<td>0.647</td>
</tr>
<tr>
<td>adj. R-sq</td>
<td>0.518</td>
<td>0.548</td>
<td>0.556</td>
<td>0.524</td>
<td>0.598</td>
<td>0.642</td>
</tr>
</tbody>
</table>

Notes: Standard errors in parentheses; + p < 0.10, * p < 0.05, ** p < 0.01. (M) indicates the variables are measured in millions of units. R² in the 2SLS estimation is based on Pesaran and Smith (1994).
We further explore how STDM performs in explaining the fares at different fare percentiles. To gain deeper insight into the effects of HHI and STDM across the different fare percentiles, we estimate the full specification of equation (1) with both HHI and STDM, for a number of other percentiles; from the 5th to 95th in 5 percentile increments as well as the 1st and 99th percentiles. The estimated coefficients of HHI and STDM are illustrated in Figure 6 along with their degree of significance.24

Figure 6. Effect of HHI and STDM at different transacted fare percentiles

The coefficients from Figure 6 show the effects of HHI and STDM on the transacted fares at the different quartiles are aligned, to a limited degree. Overall, the coefficients of the STDM reveal a U-shaped behavior indicating that the effect is more pronounced in the low percentiles as well as in the high percentiles while tending to be less pronounced in the intermediate percentiles. The coefficients of HHI exhibit an increasing upward trend in the percentiles, yet, become significant only at the medium and higher fare percentiles. Importantly, this would indicate that scheduling of flights (as measured by STDM) is a more important factor in driving transacted fares than is market structure (as measured by HHI) for many of the fare percentiles. That is, the manner in which fares are established, is due more to the degree of schedule overlap than to market share.

---

24 For most fare percentiles we have the complete sample of 642 markets. However, for the lower percentiles (1-20) the number of observations decreases, as some of the fares at those percentiles are zero (possibly free tickets or purchased by bonus miles). Specifically, at the 1st percentile almost half of markets in the sample have zero fare tickets. There are 86 markets with zero fares at the 5th percentile and only few (1 to 11) of the markets have zero fares for the 10th-20th percentiles.
One possible explanation to the U-shape of the values of the coefficients of STDM and the lack of significance of the HHI at the lower percentiles is that an increase in the value of the STDM coefficient indicates that airlines seek to differentiate from each other by offering products, flights, that are as far apart from those of their counterparts in the market or by offering a unique composition of flights that are spread throughout the day to meet the demands of time sensitive passengers. This strategy is effective in the higher percentiles, as it possibly attracts the higher yield business travellers and allows the airline to extract a higher fare premium. This strategy also seems to be effective in the lower fare percentiles; product differentiation through flight timing allows the airlines to extract higher fares from their passengers at this range of fare percentiles. At the middle range the effect of STDM is low while the effect of HHI is significant. This is possibly where product differentiation is not influential in increasing revenue while market structure drives the airlines to exercise competitive revenue management techniques. Indeed, Chandra and Lederman (2015) state that middle fares are the range which are mostly affected by the revenue management strategies.

Market structure may play a role in the degree of information the STDM captures in markets as the coefficient of the LCCDummy changes in the different fare percentiles. The analysis above also suggests that schedule overlap may play a different role for different passenger types. Accordingly, we further explore the impact driven by the rivalry structure between the airlines in the market.

6.2. The effect of the duopoly structure

To explore the duopoly structure, we distinguish between markets where both competing carriers are network carriers (in which case LCC=0), where both are low cost carriers (in which case LCC=1), and when we have a mixture of both (where 0<LCC<1). We estimate specification (3) separately for each of these market structures and illustrate the coefficients of HHI and STDM in the three panels of Figure 7.25

The first observation is that once we account for the market structure, the effect of HHI completely vanishes indicating that market concentration could very well be an outcome of the mix of business models. Namely, the type and extent of rivalry between carriers depends on

25 We have estimated all three model specifications, but we only report specification (3) as it has the most explanatory power as discussed earlier.
whether a carrier is competing with an LCC, or with a network carrier, and defines the intensity with which they compete in terms of sharing the market.

The second observation is that the coefficients of STDM, and the significance, depend on the market structure. When both competing airlines are low cost carriers, STDM has absolutely no power in explaining the fares at the different percentiles. This result is driven by the fact that in such markets the schedule of flights plays minimal or no role, in customers’ choices; an LCC rivalry is essentially a price-based competition.

When at least one of the competing firms is a network carrier, we observe the importance of STDM in explaining the transacted fares in the different percentiles. When both airlines are networks carriers, the effect of STDM is rather consistent (with a slight decrease in the coefficients as the percentile increases) across the fare percentiles. When the rivalry is between an LCC and a network carrier, the shape of the STDM is distinctively U-shaped. The impact of differentiating the product on schedules decreases from lower to middle percentiles and then increases towards upper percentiles. Clearly, schedule differentiation plays a role in the competition between a network carrier and an LCC; as the two focus on fundamentally different strategic variables — with one focusing on price and the other focusing on service, or schedules in our case—we observe how this dimension is reflected in the impact of our measure, STDM. The impact of STDM is most pronounced at the higher fare percentiles where the network carrier can extract a premium from time-sensitive business travellers. In the middle range the effect is reduced as the competition between the LCC and network carrier is most intense as the two carriers compete over the same segment of consumers. The lower range is possibly dominated by the LCC, which generally differentiates its schedule from that of the network carrier, and this differentiation, in turn, is reflected in the higher coefficients of STDM. Perceived differently, if the LCC were not to differentiate from the network carrier, their competition in the lower fare percentiles would be more intensive resulting in even lower fares. Hence, even the LCC can see a benefit from charging higher fares by separating its schedule away from that of the network carrier.
Figure 7-a. Two network carriers

Figure 7b. One Network and One LCC
7. Discussion and concluding remarks

Measuring competition is a central part of market assessment carried out by both anti-trust authorities and policy makers (such as for antitrust purposes or broader policy initiatives, including liberalizing international bilaterals) and decision makers in the private sector (such as market entry, positioning, and differentiation). Traditional methods of measuring competition (e.g., HHI) can overlook the rivalry between competing firms in that they ignore the way that firms compete with each other. For instance, firms can compete by (vertically and horizontally) differentiating their services and segmenting the demand. Understanding this differentiation can reveal the degree of competition by accounting for the way that firms compete, rather than merely capturing their respective market shares.

In aviation markets, vertical differentiation between firms is often the strategic choice of an airline when determining whether to operate as a network carrier, which emphasizes service, or as a low cost carrier, which emphasizes lower fares. Such differentiation often supports the segmentation between price sensitive, leisure passengers and time sensitive and service driven business passengers. Airlines also differentiate themselves horizontally, to some degree, by scheduling their flights at different time slots throughout the day. This scheduling differentiation can further support demand segmentation as some travellers may be time sensitive due to their
own schedules of meetings, whereas other travellers may be rather indifferent to the timing of the flight.

Our STDM captures important aspects in the competition between service providers, and as demonstrated via the aviation example described in this article. STDM measures the degree of overlap between competing schedules by accounting for both the frequency of operations in the market as well as for the substitution between flights operated by competing airlines. In our analysis we have provided compelling evidence that the STDM is an important instrument in assessing the degree of competition in markets. Specifically, we have shown that by accounting for STDM the predictive power of our models, based on adjusted $R^2$, has improved by 3-8 percentage points. The STDM explains fare levels above and beyond fare levels captured by the market concentration variable, HHI. An increase in STDM, which could reflect a reduction in the numbers of flights and/or a decrease in the substitutability of the competing airlines’ schedules, results in higher average transacted fares. This is intuitive, yet, this feature has not been captured previously in competition measures. Thus, keeping the level of HHI in a market fixed, the value of STDM may change, if, for example, both airlines increase their frequency by one additional flight. Since this affects their degree of overlap, the dynamics of the change will command a correction in the transacted fares in this market.

The STDM also plays a significant role in explaining fares across the different fare percentiles. We found that the coefficients of STDM exhibit a U-shaped relationship with respect to the fare percentiles.26 This outcome along with the insight that market structure possibly interacts with STDM has led us to distinguish among three duopoly structures: one where both firms are network carriers, another where both are LCCs, and a third where one is a network carrier and the other is an LCC. The analysis has provided fundamental insights on the role of STDM in the various duopoly market structures, while suggesting that HHI is insignificant when the markets are classified based on the duopoly structure. LCCs have a low fare strategy and capture the more elastic lower yield demand segments. Hence, in markets with only LCC rivalry, STDM plays no role, as LCCs compete primarily on price (and not on providing adequate schedules). Network carriers structure their schedules to focus primarily on high yield (fare) passengers as well as other

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26 This can possibly be interpreted as having the intensity of competition among carriers concentrated at the mid fare levels. As Chandra and Lederman (2015) point out, competition has very little impact on cheap tickets and high price tickets but it does impact fares in between. Their findings are consistent with our percentile results as well.
more elastic segments on the demand function. Therefore, for network carriers, the degree of schedule overlap, as captured by the STDM, has an impact on fare levels. When two network carriers compete, the effect of STDM is consistent across the different fare percentiles in measuring the impact on fares. When a network carrier competes with an LCC, the two manage to differentiate their flights away from each other to reduce substitutability.

Our STDM is an innovative approach to measure market competition and product differentiation in schedule industries with a focus on the airline industry. The results highlight important aspects of competition intensity in the context of aviation markets. For management, it reveals when and how schedule overlap is important in facilitating higher fares. For policy makers, our insights can stimulate more careful construction of aviation policies as the impact of schedules and their degree of overlap can influence transacted fares in substantial ways that complements the traditional measure of market concentration, HHI. For instance, a regulator might impose constraints on the number of flights, or the timing of flights, until competition results in a reduction of fares to consumers.

Another implication of STDM relates to airport slot management. Extending our framework can yield further insights into the management of slots at slot controlled airports in ways that weighs efficiency vs schedule overlap in optimal ways. One can also extend the analysis to merger and acquisition approvals, which are oftentimes subject to the giving up of landing slots at airports. In such cases the approval may not only determine the number of slots to be released (based on HHI analysis) but may also indicate which slots should be released (based on STDM analysis) and the way that measures of economic welfare are affected.
References


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Appendix

Our final analysis explores the magnitude of the effect of STDM on the realized dispersion of fares in the various markets. To that end, we construct a commonly used fare dispersion measure: lnGiniOdds, which is the log odds of the Gini coefficient. The estimation results with lnGiniOdds as the dependent variable are provided in Table A1. Overall, we find that STDM is significant in explaining the dispersion of fares. The structure of the market as reflected in HHI explains fare dispersion. The general result, from the literature, is that less fare dispersion occurs under more competitive market structures because it is harder to price discriminate. Bornstein and Rose (1994) found that fare dispersion increases with competition, leading to the conclusion that brand loyalty leads to price discrimination. The more recent article of Gerardi and Shapiro (2009) found the opposite, and more common, result that fare dispersion decreases under competition. Chandra and Lederman (2015) find that competition increases fare dispersion across cross-cabin fare differentials (economy and business) but reduces fare differentials amongst discount coach passengers. STDM exhibits a U-shaped behavior across the fare percentiles, and this could possibly explain the role of STDM with respect to fare dispersion.27

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27 This somewhat echoes Chandra and Lederman (2015) who note that competition has very little impact on cheap tickets and high price tickets but it does impact the fares in middle.
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Notes: Standard errors in parentheses; + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. (M) indicates the variables are measured in millions of units.