Dynamic pricing mechanisms for the airline industry: a definitional framework

Dynamic Pricing Mechanisms for the Airline Industry: A Definitional Framework

Michael D. Wittman[a,1] and Peter P. Belobaba*[a,2]

* Corresponding author

[a] Massachusetts Institute of Technology, International Center for Air Transportation,
77 Massachusetts Avenue, Building 35-217, Cambridge, MA 02139
Email: wittman@mit.edu; belobaba@mit.edu

[1] holds a Ph.D. in Air Transportation Systems from MIT, where his research focused on dynamic pricing in airline revenue management, airport connectivity, and "capacity discipline" in the U.S. aviation market. His work on dynamic pricing has won awards and recognition from AGIFORS and the INFORMS Aviation Applications Section. He has recently started in a new role in revenue management research at Amadeus.

[2] is Principal Research Scientist at MIT, where he teaches graduate courses on the Airline Industry and Airline Management. He is Program Manager of MIT's Global Airline Industry Program and Director of the MIT PODS Revenue Management Research Consortium. He holds a Master of Science degree and a PhD in Flight Transportation Systems from MIT. He has worked as a consultant on revenue management systems at over 50 airlines and other companies worldwide.

Dynamic Pricing Mechanisms for the Airline Industry: A Definitional Framework

Michael D. Wittman and Peter P. Belobaba

Abstract

The phrase "dynamic pricing" has entered the airline revenue management lexicon in recent years with the emergence of new distribution capabilities that could allow airlines to adjust ticket prices more frequently. Yet each airline, vendor, and academic has a unique (and often incongruous) view of what dynamic pricing encompasses. To date, there has not been a definition of dynamic pricing proposed in the literature that clearly delineates how these mechanisms are different from traditional airline pricing and revenue management.

In this paper, we propose a definitional framework for dynamic pricing for the airline industry. After providing a general definition of dynamic pricing, we describe three mechanisms for price selection—assortment optimization, dynamic price adjustment, and continuous pricing. Depending on the implementation and the information available to the airline at the time of pricing, each of these mechanisms could be used to adjust prices relatively infrequently or, at the limit, on a transaction-by-transaction basis. We close by linking recent technological developments in airline pricing, revenue management, and distribution to the three mechanisms introduced in the framework.

Keywords: dynamic pricing, airline revenue management, dynamic pricing engines, New Distribution Capability, continuous pricing

INTRODUCTION

The phrase "dynamic pricing" has appeared frequently in recent years in the airline revenue management (RM) literature. Academics, practitioners, and travelers seem to agree that this phrase describes a situation in which the price of a flight itinerary quoted to consumers changes over time. Yet despite many academic articles, news stories, and vendor publications about dynamic pricing, the industry lacks a clear and consistent definition of what exactly dynamic pricing is.

Some authors define dynamic pricing broadly as "a set of pricing strategies aimed at increasing profits" (McAfee and te Velde, 2006), or conflate it with traditional airline RM practices (Escobari, 2012; Williams, 2018). This latter classification may certainly appear reasonable. Most travelers know from experience that the price of a flight can change many times prior to departure: from their perspective, airlines appear to be practicing "dynamic pricing" already.

For other authors, dynamic pricing represents an evolutionary leap from the pricing and RM practices used by airlines today. Fiig et al. (2016) describe dynamic pricing as a "dynamic calculation of the optimal price, taking into account the airline's strategy, customer-specific information, and real-time alternative offerings," while Kumar et al. (2018) view dynamic pricing as "varying pricing over a continuous interval instead of opening and closing fare classes." Under this latter definition, dynamic pricing would not be possible using traditional airline distribution technologies, which transmit and display the availability of a small number of pre-priced fare products.

With recent industry agreement to move toward the New Distribution Capability (NDC) standards developed by the International Air Transport Association (IATA), airlines will soon have the ability to receive and respond to booking requests from all distribution channels in real-time. NDC will enable airlines to dynamically generate and distribute a series of "offers" in response to each search request (Harteveldt, 2016). Unlike traditional airline distribution standards, the prices of offers distributed through NDC need not be tied to a set of pre-determined price points. The impending use of these new standards has increased the interest of virtually all industry stakeholders in the development of new mechanisms for "dynamic pricing."

However, there has been no agreement on how to define "dynamic pricing" in the airline industry. Some see dynamic pricing as a practice that is already firmly in place, while for others it represents a futuristic ideal requiring new technology and new science. This disconnect exists partially because many past definitions of dynamic pricing have been too narrow in scope. In this paper, we aim to address this deficiency in the literature by describing a definitional *framework* for dynamic pricing mechanisms.

Our framework describes three mechanisms for dynamic pricing in the airline industry: assortment optimization, dynamic price adjustment, and continuous pricing. Each of the mechanisms allows an airline to adjust its prices over time in response to changes in an "observable state of nature," which could include remaining inventory, forecasts of future demand, competitor behavior, and/or detailed information about the individual shopping session. Depending on its technological capabilities and its commercial strategy, the airline could choose to change prices infrequently or, at the limit, select a unique price for each transaction.

While some of the dynamic pricing mechanisms described in the framework are feasible under current distribution standards, others require the development of new technologies. For each mechanism, we discuss the scientific and technological developments currently underway within the airline industry to operationalize the mechanism.

Note that our focus in this paper is to classify the *mechanisms* for dynamic pricing, as opposed to the scientific *methods* or algorithms used to select which price to display. Readers interested in a review of the mathematics of dynamic pricing may wish to consult Elmaghraby and Keskinocak (2003), den Boer (2015), Chen and Chen (2015), and Wittman (2018).

A DEFINITIONAL FRAMEWORK FOR DYNAMIC PRICING MECHANISMS

As opposed to static pricing, *dynamic pricing* implies that prices for the same product may change over time. We begin with a general definition of dynamic pricing that captures this key idea.

> **Definition: Dynamic Pricing (Wittman and Belobaba, 2018)**
> Firms practice *dynamic pricing* when they charge different customers different prices for the same product, as a function of an observable state of nature.

The *observable state of nature* in the definition above refers to the set of information available to the firm at the time of pricing. This could include the remaining product inventory, the time remaining in the selling period, and a forecast of future demand. Specific information about each individual transaction may also be available in the observable state of nature: for instance, the characteristics of the shopping request or the price and quality of competitor offerings. Changes in the observable state of nature may (or may not) cause the firm to offer a different price for the product.

Note that dynamic pricing need not result in different prices for each individual transaction. Some firms may change their prices relatively infrequently, such as on a daily or weekly basis. At the other extreme, firms practice *transactional dynamic pricing* when they select prices for each shopping request based on the characteristics of the request or, at the limit, of the individual customer making the request.

Firms practicing dynamic pricing can use different mechanisms to adjust prices from transaction to transaction. We propose three such mechanisms: assortment optimization, dynamic price adjustment, and continuous pricing.

ASSORTMENT OPTIMIZATION

One common price selection mechanism involves first defining a finite set of possible price points and then selecting which of these price points to make available in response to shopping requests. We call this technique *assortment optimization*.

Definition: Assortment Optimization

In *assortment optimization*, firms select one or more prices from a finite menu of possible price points. Each price point may be associated with various rules or restrictions that determine how or when that price can be selected. The menu of price points may be updated periodically, but there is only a limited and discrete set of possible prices that can be selected at any given time.

The phrase "assortment optimization" has a rich history in the operations research literature, where it is typically used to describe the constrained optimization problem faced by retailers selecting a subset of their products to display for sale (Kök et al., 2008). A supermarket's decision of which products to place on an endcap display and an online shopping portal's choice of advertisements to show at the top of a web page would both be examples of assortment optimization.

The assortment optimization decision is typically made subject to inventory and display constraints. In both online and offline contexts, firms can display only a finite number of products to a customer, and these products may be subject to limited selling seasons or stock outs. As the remaining inventory or time remaining in the selling season decreases, these changes in the observable state of nature could cause the firm to display different assortments of products or prices.

Traditional airline pricing and revenue management is a clear example of assortment optimization. The "products" optimized in airline RM are the pre-priced fare classes defined by the airline's pricing department. If an airline has ten fare classes for sale in a given cabin in a given market, the airline's assortment optimization problem is deciding which subset of these classes to "display," or make available, to its customers.

In some cases, the airline's fare classes may be differentiated through the use of fare restrictions, such as non-refundability, minimum stay, or advance purchase requirements. In other cases, the fare classes may be homogeneous, and vary only in price. In all cases, the key feature of the assortment optimization problem is the relatively small and finite menu of possible price points from which the airline selects its prices.

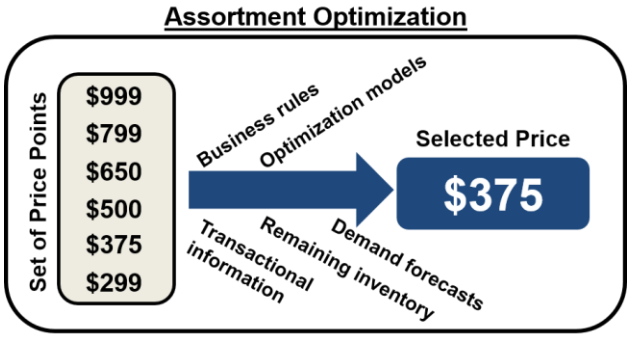

FIGURE 1: Schematic of Assortment Optimization

Figure 1 shows a simple schematic of assortment optimization. In the figure, the firm begins by defining a set of six possible price points, ranging from $299 to $999. In practice, this set of price points is often defined based on market conditions: based on the number of competitors in the market, or the prices that competitors offer for similar

products. The firm then selects one of these pre-defined price points to display to the customer—in this case, $375.

The price selection process is typically managed through business rules that govern when particular price points can be made available. A particular price point may only be available if purchased far in advance, if the product cannot be returned or refunded, or if the customer is a senior citizen. Along with these simple business rules, firms can also use mathematical optimization models to determine which price point to display at a given time, as a function of a demand forecast and the remaining inventory.

Most airlines optimize their assortment of available fare classes relatively infrequently, at designated Data Collection Points (DCPs) in their RM system, or in some cases daily. Prices could instead be selected from the menu for each transaction individually, depending on the characteristics of the transaction or the customer. We call this real-time selection of prices *transactional assortment optimization*. Recent advancements in "dynamic availability," in which the availability of a fare product may change depending on the characteristics of each shopping request, is an example of such a mechanism in the airline industry (Toyoglu et al., 2018).

Firms practicing assortment optimization can periodically update their menus of possible price points in response to changes in market conditions. This could be done by adding or subtracting price points from the menu, altering the rules and restrictions associated with each price point, or changing the values of the prices in the menu. In the airline context, this process takes the form of filing new fares. The price displayed for any individual transaction is always selected from the finite set of price points that is valid at the time.

Under traditional pricing and RM practices, airlines adjust the prices and/or rules of fare products to reflect changes in the marketplace—for instance, if a new competitor enters a market, or if a competitor changes their own set of possible price points. The frequency of changes to airline fare structures has increased in recent years through improvements in technology, and many thousands or millions of price changes per day are now possible (Konanki et al., 2017). Yet as long as airlines select prices from among a relatively small, discrete set of possible options for each transaction, they are practicing assortment optimization.

DYNAMIC PRICE ADJUSTMENT

A firm may sometimes wish to offer a price that is not included in its pre-defined set of possible price points. The firm could update or adjust the menu of price points and continue to practice assortment optimization. However, in some cases it may not be necessary, desirable, or feasible to make this type of change to the menu of price points—for instance, if the new price point is offered only for a certain segment of customers, or is only valid for a limited time.

Suppose a firm wishes to give certain customers a discount of 10% off the normal price of its products. The firm could do so by first selecting a price using the assortment optimization approach described above, and then dynamically applying the discount only for customers or shopping requests that fit certain criteria.

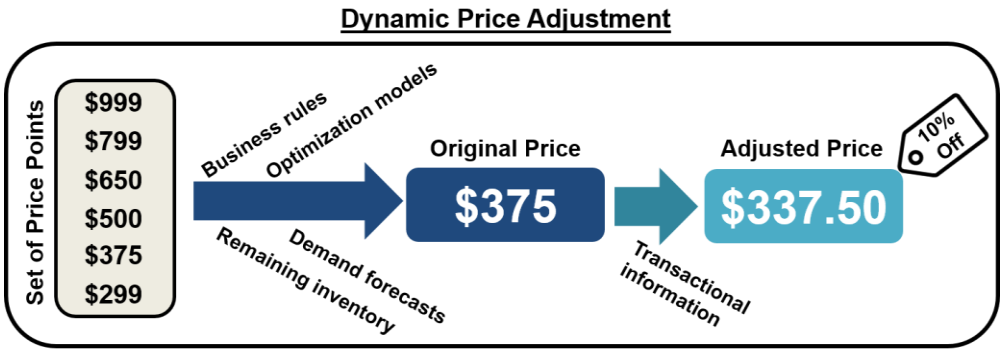

FIGURE 2: Schematic of Dynamic Price Adjustment

For example, in Figure 2, the firm selects a price of $375 through its assortment optimization process and then applies the 10% discount to transactions that fit the relevant criteria. This allows the firm to offer the price of $337.50, which is not listed in the set of pre-defined price points, to certain customers. Shopping requests that do not meet the criteria to receive the discount are offered the original price of $375. We call this approach *dynamic price adjustment*.

Definition: Dynamic Price Adjustment

With *dynamic price adjustment*, firms start by selecting a price from a pre-defined menu of possible price points, as in assortment optimization. Then, for certain customers or in certain situations, this price is adjusted through either a discount or an increment. All adjustments are made in reference to a price from the fixed menu, and some customers may be shown an unadjusted price.

As in assortment optimization, firms using dynamic price adjustment begin with a pre-defined, relatively small set of possible price points. These price points could be associated with various rules and restrictions that govern their applicability. After selecting a price point using the assortment optimization approaches described in the previous section, the firm can choose to adjust that price. The adjustment takes the form of a discount or an increment relative to the price selected from the menu. The amount of the adjustment could change from transaction to transaction. Transactions that are not eligible for a discount or increment are shown the unadjusted price from the menu.

The dynamic price adjustments could be computed infrequently (for instance, a flash sale that applies to all customers at a specific time) or, at the limit, for each transaction individually. Firms using dynamic price adjustments could decide whether or not to explicitly display the price adjustment to customers. Marketing research has shown that framing prices in terms of discounts can change customer purchasing intentions and perceptions of price fairness (Weisstein et al., 2013; Lehtimäki et al., 2018).

In the airline industry, dynamic price adjustment has to date been infeasible due to the legacy technologies that airlines use to distribute and sell their products. These distribution standards were designed for assortment optimization, where prices are selected from a small set of pre-defined price points. However, with the advent of the New Distribution Capability (NDC) and other new standards for airline distribution, dynamic price adjustment is becoming increasingly feasible.

A working group convened by the Airline Tariff Publishing Company (ATPCO) has

proposed new technological standards for so-called "Dynamic Pricing Engines" (DPEs; Delezak and Ratliff, 2018). With the proposed DPE standards, airlines could mark-down or mark-up pre-filed fares for certain shopping requests. Since airlines still use a finite, pre-determined set of possible price points (and existing pricing and revenue management techniques) to complete their initial price selection, and since some customers may be shown an unadjusted fare, this mechanism represents an example of dynamic price adjustment. Recent research has suggested that this type of dynamic pricing could lead to revenue benefits for airlines (Wittman and Belobaba, 2018; Kumar et al., 2018).

CONTINUOUS PRICING

Continuous pricing represents the most flexible practice that firms can use to set prices. With continuous pricing, prices are selected from a continuous range of possible values, as shown in Figure 3. Any price point within the range is feasible for selection—for instance, in Figure 3, any value between $299 and $999 mays be chosen. Unlike assortment optimization or dynamic price adjustment, continuous prices are not linked to a finite set of prices that the firm defines in advance.

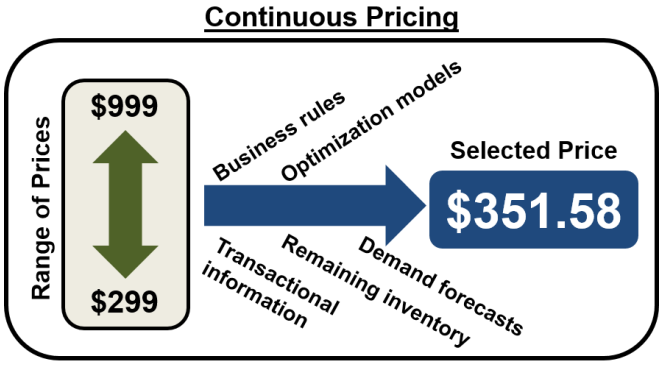

FIGURE 3: Schematic of Continuous Pricing

Definition: Continuous Pricing
With *continuous pricing*, firms select a price from a continuous range of possible values. There is no underlying finite menu of possible price points, although there may be business rules that determine the range of allowable prices at any moment. At the limit, dynamic prices could be generated individually for each transaction (transactional dynamic pricing). However, prices do not necessarily need to differ from transaction to transaction.

Although continuous pricing provides firms with many more possible price points than assortment optimization, the scientific method used to select the optimal price may be similar to those used by other dynamic pricing mechanisms. Firms using continuous pricing can select prices by incorporating business rules, mathematical optimization models, information about remaining inventory or forecast demand, and/or transaction-specific data. As with other methods, firms using continuous pricing can complete the price selection process infrequently or, at the limit, on the transactional level.

Transactional continuous pricing, in which prices are selected from a continuous range for each individual transaction, represents one of the most complex forms of pricing that

can be practiced by firms. This practice requires detailed contextual information about each transaction and sophisticated rules or mathematical algorithms to select prices as a function of this information. It also requires a technological pathway to compute, distribute, and display the transaction-specific price to each shopping request in real time.

Since continuous prices are not tied to pre-filed fare products, continuous pricing is not feasible for indirect distribution channels given current standards. The development of NDC has given rise to the possibility of a "world without fare classes" (Westermann, 2013), but this future world would require significant changes to internal and external airline pricing, revenue management, and distribution processes.

CONCLUSIONS

This paper has proposed a definitional framework for dynamic pricing mechanisms in the airline industry. We first presented a general definition for dynamic pricing, in which firms charge different prices to different customers for the same product, as a function of the available information at the time of pricing. We then described three mechanisms that firms can use to practice dynamic pricing, summarized in Figure 4.

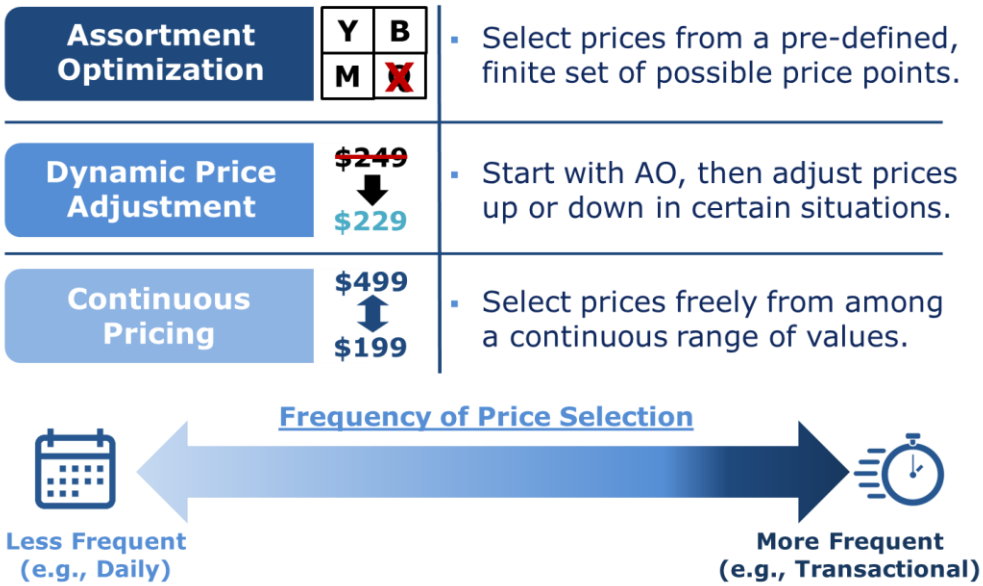

Figure 4: Mechanisms for Dynamic Pricing

- With *assortment optimization*, airlines select prices from among a relatively small menu of pre-defined price points. Each of the price points could be associated with internal or external rules and restrictions that determine when they can be selected. Airlines can periodically update the menu of price points, but only the prices included within in the menu can be selected and displayed to customers at any particular time.
- With *dynamic price adjustment*, airlines begin with a pre-defined menu of possible price points, as in assortment optimization. After selecting one of the pre-defined prices, airlines can increment or discount this price for specific customers or in specific situations. These adjustments, which could vary from transaction to transaction, are made relative to the pre-selected price point. This allows airlines to offer prices outside of the pre-defined menu, although some customers may

receive unadjusted prices.

- With *continuous pricing*, airlines select prices from a continuous range of possible values. There is no finite menu of possible price points; any price within the range can be chosen.

With any dynamic pricing mechanism, airlines have a choice of how often they wish to update their selected price. Prices could be selected infrequently, such as on a weekly or monthly basis, or more frequently, such as daily or multiple times per day. At the limit, prices could change from transaction to transaction as a function of information about the shopping request, competitor offerings, or remaining inventory. The frequency of price selection is dependent not only on the degree of technical sophistication of the airline, but also on how much contextual information the airline has about each transaction.

We also discussed how recent technological developments relate to the mechanisms in the framework described above. Traditional airline pricing and revenue management is clearly an assortment optimization problem, with airlines publicly filing a set of pre-priced fare classes and then determining which of these fare classes to make available to each customer. "Dynamic availability" technologies have allowed airlines to determine fare class availability on a transactional basis, and to update the set of filed fares more frequently.

For dynamic price adjustment, an ATPCO working group has recently proposed standards for so-called Dynamic Pricing Engines that would allow airlines to increment or discount the prices of pre-filed fare products. The proposed standards have moved to a pilot phase with airlines and vendors, suggesting that this mechanism could soon be within the reach of airlines.

Finally, continuous pricing is infeasible in the current world of class-based distribution, and would require the implementation of an NDC-based offer management system across many distribution channels. This new distribution concept would discard the idea of pre-filed fare classes and allow airlines to freely select the prices they charge—perhaps changing from transaction to transaction level. While the technological barriers to continuous pricing are quite high, this mechanism could represent a revolution in the practice of pricing and revenue management in the airline industry.

ACKNOWLEDGMENTS

A version of this framework first appeared in a PODS Research LLC discussion paper prepared for ATPCO (Belobaba et al., 2017). The authors wish to thank Tom Gregorson, Dan Zawack, Ellen Runyon, and Rolf Purzer for their valuable feedback and for their encouragement to publish the framework as a standalone article. The authors also thank Bill Brunger for his contributions to the discussion paper in which this framework first appeared.

REFERENCES

Belobaba, P.P., W.G. Brunger, and M.D. Wittman. 2017. Advances in Airline Pricing, Revenue Management, and Distribution: Implications for the Airline Industry. Working Paper. Prepared by PODS Research LLC for the Airline Tariff Publishing Company (ATPCO).

Burger, B. and M. Fuchs. 2005. Dynamic pricing—A future airline business model. Journal of Revenue and Pricing Management 4(1): 39-53.

Chen, M. and Z.-L. Chen. 2014. Recent Developments in Dynamic Pricing Research: Multiple Products, Competition, and Limited Demand Information. Production and Operations Management 24(5): 704-731.

Delezak, M. and R. Ratliff. 2018. Towards new industry-standard specifications for air dynamic pricing engines. Journal of Revenue and Pricing Management. Published online 28 March 2018.

den Boer, A.V. 2015. Dynamic pricing and learning: Historical origins, current research, and new directions. Surveys in Operations Research and Management Science 20(1): 1-18.

Elmaghraby, W. and P. Keskinocak. 2003. Dynamic Pricing in the Presence of Inventory Considerations: Research Overview, Current Practices, and Future Directions. Management Science 49(10): 1287-1309.

Escobari, D. 2012. Dynamic Pricing, Advance Sales and Aggregate Demand Learning in Airlines. The Journal of Industrial Economics 60(4): 697-724.

Fiig, T., O. Goyons, R. Adelving, and B. Smith. 2016. Dynamic pricing—The next revolution in RM? Journal of Revenue and Pricing Management 15(5): 360-379.

Harteveldt, H.H. 2016. The Future of Airline Distribution, 2016-2021. Prepared by Atmosphere Research Group for the International Air Transport Association.

Kök, A. G., M. Fisher, and R. Vaidyanathan. 2008. Assortment planning: Review of literature and industry practice. In: Retail Supply Change Management. Eds. N. Agarwal and S.A. Smith. Springer, pp. 99-153.

Konanki, R., B.R. Guntreddy, O. Oancea, and G. Komirishetty. 2018. Quantum Pricing: Dynamic Pricing in Action. Proceedings of the 2017 AGIFORS RM Study Group Meeting, San Francisco.

Kumar, R., A. Li, and W. Wang. 2018. Learning and optimizing through dynamic pricing. Journal of Revenue and Pricing Management 17(2): 63-77.

Lehtimäki, A.-V., K.B. Monroe, and O. Somervouri. 2018. The influence of regular price level (low, medium, or high) and framing of discount (monetary or percentage) on perceived attractiveness of discount amount. Journal of Revenue and Pricing Management. Published online 03 May 2018.

McAfee, R.P. and N. te Velde. 2007. Dynamic Pricing in the Airline Industry. Working Paper, California Institute of Technology, Pasadena.

Toyoglu, H., A. Agarwal, and M.R. Kummara. 2018. Dynamic Availability. Proceedings of the 2018 AGIFORS RM Study Group Meeting, Hong Kong.

Weisstein, F.L., K.B. Monroe, and M. Kukar-Kinney. 2013. Effects of price framing on consumers' perceptions of online dynamic pricing practices. Journal of the Academy of Marketing Science 41(5): 501-514.

Westermann, D. 2013. The potential impact of IATA's New Distribution Capability (NDC) on revenue management and pricing. Journal of Revenue and Pricing Management 12(6): 565-568.

Williams, K.R. 2018. Dynamic Airline Pricing and Seat Availability. Cowles Foundation Discussion Paper No. 2103U, Yale University, New Haven.

Wittman, M.D. 2018. Dynamic Pricing Mechanisms for Airline Revenue Management: Theory, Heuristics, and Implications. Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Wittman, M.D. and P.P. Belobaba. 2018. Customized dynamic pricing of airline fare products. Journal of Revenue and Pricing Management 17(2): 78-90.

Zhang, D. and Z. Lu. 2013. Assessing the value of dynamic pricing in network revenue management. INFORMS Journal on Computing 25(1): 102-115.