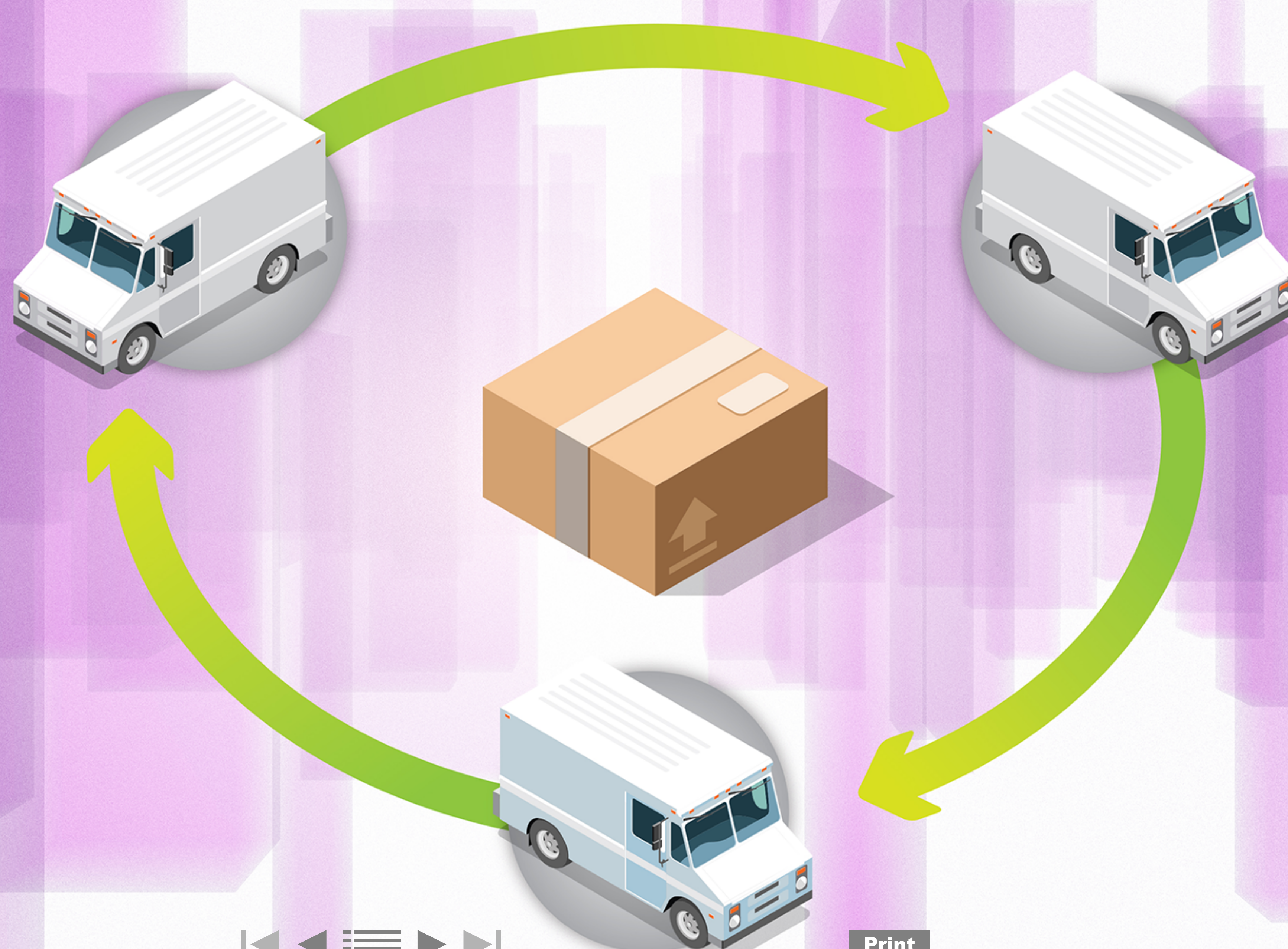
OFFICE OF INSPECTOR GENERAL
UNITED STATES POSTAL SERVICE

Play to Win: Competition in Last-Mile Parcel Delivery



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Executive Summary

The parcel market has undergone great change over the last decade. It was once a relatively simple market with three key players — the Postal Service, FedEx, and UPS — competing over a predictable and manageable level of parcel volume with few concerns about capacity. While the three competed fiercely for business-to-business parcel volume, FedEx and UPS were generally less interested in residential delivery.

It is now a more complicated market. The rise of ecommerce led to a tremendous growth in parcel volume delivered to residential homes. This rapid growth in online shopping made residential delivery more attractive to UPS and FedEx, and therefore increased competition between the big three. In addition, the rise in online orders heightened customer expectations in terms of price, place, and time of delivery, which at times tested the flexibility and capacity constraints of the big three. Over time new, smaller, flexible, and technologically-advanced parcel delivery firms began to enter the market to take advantage of the new growth. Eventually, a few large retailers came to dominate the online shopping market, and they used their purchasing power to keep delivery prices low. Recently, despite low delivery prices, these large retailers have begun to venture into self-delivery.

These changes, especially the threat of last-mile delivery by retailers, have not only increased the competition in the parcel market, but have also changed the dynamics within the market — so much so that the relationship between the players has been turned on its head. Not only does the Postal Service often provide last-mile delivery for FedEx and UPS, but now they are all in competition together against the large retailers move into self-delivery. Previously, the Postal Service, FedEx, and UPS played a kind of zero-sum game in which an increase in Postal Service delivery volumes implied a reduction in packages delivered by FedEx and UPS. In the current parcel market, there are circumstances where an increased postal presence can actually increase the volume of packages delivered by FedEx and UPS. With increased competition, and the associated drop in price, the large retailer may have no economic incentive to enter the self-delivery business.

Highlights

The parcel market has evolved rapidly over time, significantly altering the relationship among the players.

The parcel market used to be a zero-sum game where growth in parcel delivery by one entity meant a reduction in parcel delivery by competing firms.

In his theoretical model, Professor Panzar shows that large parcel delivery companies are threatened by more than competition amongst each other — their real battle is over package volumes under the threat of self-delivery by large retailers.

With these thoughts in mind, the U.S. Postal Service Office of Inspector General (OIG) asked Professor John Panzar, an expert in postal economics from Northwestern University and the University of Auckland, to provide a theoretical model on the modern parcel market. While abstract models such as this one are not prescriptive, they can guide the strategic thinking of decision makers in several ways. The model can help to organize efficiently all the assumptions about these relationships in a consistent framework, a framework that can be adjusted with shifts in business realities. Theoretical models provide a low-cost way of looking at various what-if scenarios and can help decision makers make better, more timely, practical decisions and design workable strategies. Waiting to observe actual experience to make strategic decisions would be too costly — both in terms of time and opportunities lost.

Professor Panzar models the parcel market, assuming four main players: a postal provider (the post), two parcel delivery services that enjoy a duopoly (referred to as FPS and UX), and a large retailer with purchasing power that is capable of self-delivery (dubbed Congo). As with all theoretical models, the starting assumptions are critical to the end results. A critical assumption in this model is that the majority of the Postal Service's parcels are delivered once a day, along with letters and flats. For purposes of simplification, this is stated in the model as the Postal Service only accepting parcels for delivery in the morning.

In his model, Dr. Panzar assumes that each day Congo has parcels arriving in the morning for delivery as well as parcels arriving in the afternoon and that it makes separate delivery decisions for each. For the morning parcels, Congo makes a decision between (1) delivery by the post, (2) delivery by the FPS/UX, or (3) self-delivery. With regard to afternoon parcels, Congo only has two choices — delivery by FPS/UX and self-delivery. Congo's problem is to choose whether to buy (or lease) vans before it knows the fraction of daily volumes arriving in each time period.

The model assumes that Congo makes these decisions using basic economic criteria, that is, it chooses the option that costs less money overall. In reality, a retailer such as Congo may make these decisions based on other criteria, such as ensuring appropriate capacity to ensure service. However, eventually they would need to consider costs. Therefore, under certain price configurations, Congo will choose to deliver its own parcels. If Congo does not expect to arrange for the delivery of morning parcels at a low postal rate, they will purchase vans, and these vans would then be available for the delivery of afternoon parcels as well, thereby cutting into the volumes delivered by FPS/UX. Professor Panzar applies game theory to describe the likely pricing strategies employed in this market and the end results — who delivers the parcels and at what relative prices — using several scenarios that vary assumptions about costs.

Highlights

Though his work is theoretical, its findings have important strategic implications for the Postal Service. In the past, economic theory would have said that a simple strategy of setting postal price just slightly below its competitors' prices would work best. However, in this more evolved parcel market, the post needs to seek out a price that (in all cases) exceeds unit cost and is not only lower than the competitors' prices but also low enough to discourage Congo from self-delivery. The postal price should be set no lower than this, as any price below this point would just result in revenue leakage.

Interestingly, this pricing behavior by the post also benefits the duopoly because if the price is low enough to keep Congo from buying vans, the duopoly maintains delivery of the afternoon parcels. This insight reinforces the concept that all the parcel delivery companies, previously competing exclusively with each other, are now locked in competitive struggle with retailers' self-delivery option.

This theoretical work is not meant to provide the Postal Service with a specific pricing proposal. As with any theoretical model, it provides an abstract simplification of reality. However, it helps one to consider the implications of how players interact in an ever-changing parcel market.

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"Last Mile" Parcel Competition with Real Time Routing by Shippers

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1. Introduction and Summary

The growth in the volume of parcel delivery caused by the development of eCommerce has generated a great deal of recent discussion.[1] Substantial changes in market structure have accompanied this growth in parcel volume. These changes were made possible by the Postal Service's "unbundling" of its "last mile" delivery service. This enabled large mailers to obtain favorable rates by shipping their parcels directly to a Postal Service local delivery office. In addition, this last mile unbundling has led to increased "co-opetition" between the Postal Service and its end to end (E2E) competitors.[2] That is, rival parcel carriers increasingly use the Postal Service for the last mile delivery of parcel volumes that originated in their own upstream networks.[3] A more recent change in the parcel delivery market is for large online retailers to extend their distribution networks so that they are able to deliver their parcels directly to their

1 See, for example, various studies by the United States Postal Service, Office of the Inspector General: OIG (2011), OIG (2014), OIG (2016b) and OIG (2016c).
2 The term, "co-opetition," was popularized by Brandenburger and Nalebuff (1996).
3 I analysed a model of this type of co-opetition in OIG (2016a).

customers, thereby bypassing not only traditional E2E parcel carriers, but also the last mile delivery operation of the Postal Service.

Thus, this paper analyzes the situation facing a large parcel mailer ("Congo") that engages in flexible, "real time" routing strategies in order to deal with uncertainty in the daily arrival profile of their parcels. Congo interacts with two (or more) traditional E2E parcel delivery providers and an integrated postal operator, "the Post." For concreteness, I will refer to two such rivals as the "Federal Parcel Service" ("FPS") and "United Express" ("UX"). In addition to routing parcels via FPS, UX and the Post, Congo may engage in the "self-provision" of needed last mile delivery services using its own equipment and labor.[4]

The basic framework of the analysis is as follows. The volume of parcels received by Congo varies over the daily cycle, giving rise to a "peak load" problem. For simplicity, I model this peak load situation by dividing the "day" into two distinct sub periods: "morning" and "afternoon." As a "base load" option, Congo purchases (or rents) its own fleet of vans and uses them to deliver its parcels during both sub periods. It is natural to think of this base load technology as a network of delivery van routes following fixed schedules. Once hired, the capital components of this technology (i.e., the vans) are available for deliveries throughout the day. The associated variable costs (e.g., labor and fuel) depend on the actual number of parcels delivered. Cleary this method of parcel delivery is most efficient when dealing with balanced loads, e.g., equal volumes spread over the day. To continue the peak load analogy, Congo also has available a "peaking option" that involves contracting with the Post or its rivals to provide last mile delivery of some or all of its morning and/or afternoon parcels on a per piece basis.

By focusing on Congo's last mile shipping alternatives, I am implicitly assuming that Congo operates a large national network of warehouses and sorting centers that optimally

4 One application of the analysis deals with the situation in which the parcel delivery entities are end-to-end (E2E) common carrier rivals of the Post. In this case, a co-opetition relationship results if the Post sells "last mile" delivery access services to FPS and UX.

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distribute its merchandise from its suppliers to locations near its customers. It is at that point that Congo makes its choice between self-provision and patronizing the Post and/or its rivals.

The remainder of the paper is organized as follows. Section 2 develops the formal model of Congo's optimal dispatch problem. The analysis characterizes Congo's decisions regarding the number of delivery vans it purchases and the intensity with which it operates them as a function of the rates charged by the Post, FPS and UX. As importantly, the analysis reveals conditions under which the rates offered by the Post and its rivals are low enough to deter Congo from operating its own delivery vans. Three situations are analyzed. In the Base Case, the Post does not offer a competitive unbundled last mile service and Congo's choices are determined by the rates offered by FPS and UX. In Case 1, the Post charges a morning unbundled delivery rate between the FPS/UX rate and Congo's unit variable cost. The result is that the Post captures Congo's morning volumes that are not self-delivered, with excess afternoon volumes delivered by FPS and UX. In Case 2, the Post charges a rate that is (very, very) slightly below Congo's unit variable cost. This causes Congo to discontinue morning self-delivery.

Section 3 provides a graphical presentation of the theoretical results derived in Section 2. The discussion makes clear that, from Congo's point of view, the last mile delivery services of the Post and its rivals are *complements* for one another rather than *substitutes*. Decreasing the price of one service *increases* the demand for the other by inducing Congo to reduce the number of vans it operates.

Recognition of this fundamental complementary relationship between the Post and its rivals provides the background for understanding their competitive interactions. Section 4 provides a general discussion of the nature of the competition for Congo's last mile parcel volumes. In order to derive analytical solutions, Section 5 specifies a uniform distribution for parcel arrival times. This allows me to determine a subgame perfect Nash equilibrium outcome for the competition between the Post and its rivals. The results are summarized as follows:

(i) If competitive behavior by FPS and UX deters Congo from operating vans, the effect of entry by the Post is to efficiently capture morning parcel volumes. The rates paid by Congo remain unchanged and the Post gains profits.

(ii) If Congo finds it profitable to operate vans in spite of competitive behavior by FPS and UX, entry by the Post results in a win – win outcome. Morning parcels are efficiently shifted to the Post, Congo's delivery costs go down, and the Post gains profits.

(iii) If, initially, Congo chooses to operate its own vans when FPS and UX coordinate on the monopoly price, Post unbundled entry results in a win – win – win outcome.[5] Congo's costs go down while the profits of the parcel carriers and the Post go up because competition reduces the number of vans Congo chooses to operate.

(iv) If vans are so expensive that Congo does not operate any vans at the initial coordinated price, Post entry will be profitable and will reduce the profits of the parcel carriers, but it will not change the equilibrium rates paid by Congo.

2. Analysis of the Shipper's Real Time Dispatch Problem.

Congo receives a volume of parcels, Q, for last mile delivery in a particular local area on any given day. For simplicity, I assume that this volume is known with certainty before any routing decisions are made.[6] However, Congo does not know whether its local facility will receive the parcels during the *morning* or the *afternoon*. That is, the *proportion*, $t \in [0,1]$, of parcels available for morning delivery is a random variable, with probability density function $f(t)$ and cumulative distribution function $F(t)$. Thus, for each realization of t, the volume of parcels requiring morning delivery is given by $Q_{am} = tQ$ and the volume of parcels requiring afternoon

5 Although there is temptation to collude, this is not to suggest that FPS and UX are explicitly colluding or in violation of antitrust statutes. Firms may be able to coordinate prices via legal means, via so called *tacit collusion*. Carlton and Perloff define (p. 785) this as "the coordinated actions of firms in an oligopoly despite the lack of an explicit [illegal] cartel agreement."

6 The key assumption is that Congo is able to forecast the total daily volume of parcels more precisely than the distribution of the parcels' arrival over the course of the day.

delivery is given by $Q_{pm} = (1 - t)Q$.

Congo is assumed to have three options to use in order to meet its parcel delivery obligations:

(1) Congo can rent or purchase *K* units of van capacity for the entire day at a capital cost of *B* per unit of parcel delivery capacity. Once rented, the vans are available to make deliveries on scheduled routes in both the morning and afternoon. Van operation during either period incurs a variable (i.e., labor and/or fuel) cost of *b* per parcel.

(2) Congo can arrange for its parcels to be delivered on a per piece basis by FPS or UX at a rate of *m* for each parcel delivered. This option is available for parcels arriving in *either* the morning or the afternoon.[7]

(3) Parcels arriving for *morning* delivery can be transferred to the Post for final delivery by paying a price of *a* per unit. The Post cannot process Congo's parcels in time to meet the service standards for parcels arriving in the afternoon.

Congo can allocate the number of parcels handed off to FPS, UX, and the Post and the number it delivers using its own vans *after* it knows the intraday distribution of volume; i.e., after it observes the realization of the random variable *t*. However, it must decide on the number of vans to buy or rent *before* the day begins, when *t* remains unknown.

The analysis that follows deals with Congo's optimization problem in a *single market*: i.e., for particular values of *b* and *B*. Given the rates charged by the Post and its rivals, these cost parameters determine the extent to which Congo chooses to operate its vans for last mile delivery. In reality, however, it is likely that there is significant market – to – market variation in these costs. For example, since the costs are measured on a per parcel basis, it seems likely that per unit van costs, *B*, are much greater in low density rural areas than they are in urban areas.

7 This simple model assumes that, for Congo's purposes, the last mile services of FPS and UX are equally satisfactory: i.e., they are perfect substitutes. Therefore, the "law of one price" applies and both firms charge the same last mile delivery price, *m*.

While density effects are likely less important in determining fuel and labor per parcel costs, there might be substantial variation in *b* as well. In turn, this market – to – market variation of the cost parameters means that Congo van coverage may vary substantially across markets.

2.1 Base Case: The Post Is Not Competitive; i.e., *a* > *m*.

I begin with the analysis of the situation in which Congo cannot obtain unbundled last mile morning delivery services from the Post. Or, equivalently, the price, *a*, offered by the Post is greater than the per piece rate, *m*, available from FPS and UX. Begin by assuming that Congo has available a van capacity of *K* for use in both the morning and afternoon. Then, assuming that the variable cost of delivery using its own van is less than the price paid to FPS or UX, i.e., $b < m$, it is optimal for Congo to “fill up” its vans during each period before purchasing delivery services from FPS. Therefore, its (optimized) morning *variable* costs, $V_{am}(t,Q,K)$, for delivering $Q_{am} = tQ$ parcels in the morning are given by:

$$(1) \qquad V_{am}(t,Q,K) = \begin{cases} btQ: & t \leq \frac{K}{Q} \equiv t_{am} \\ bK + m(tQ - K): & t \geq \frac{K}{Q} \equiv t_{am} \end{cases}$$

Equation (1) reveals that Congo’s variable cost function is divided into two regions depending upon whether the realized proportion of morning arriving parcels, *t*, is less than or greater than the ratio of van capacity to total output, $K/Q \equiv t_{am}$. That is, when the number of morning parcels (tQ) is less than the amount of purchased van capacity (i.e., $tQ \leq K$, or $t \leq t_{am}$), Congo’s variable costs are just equal to the per unit variable cost of van operation times the number of parcels. When the proportion of morning parcels exceeds the ratio of van capacity to total output (i.e., $t \geq t_{am}$), Congo fully utilizes its *K* units of available van capacity, incurring variable costs of *bK*. It then resorts to the per piece option for the remaining $tQ - K$ morning parcels, incurring the additional morning variable costs of $m(tQ - K)$.

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Similarly, Congo's afternoon variable costs, $V_{pm}(t,Q,K)$, for delivering $Q_{pm} = (1 - t)Q$ parcels during the afternoon are given by:

$$(2) \qquad V_{pm}(t,Q,K) = \begin{cases} b(1-t)Q: & 1-t \leq \frac{K}{Q} \Longrightarrow t \geq 1 - \frac{K}{Q} = \frac{Q-K}{Q} \equiv t_{pm} \\ bK + m[(1-t)Q - K]: & 1-t \geq \frac{K}{Q} \Longrightarrow t \leq 1 - \frac{K}{Q} = \frac{Q-K}{Q} \equiv t_{pm} \end{cases}$$

Here, the critical proportion at which the branches of the (optimized) afternoon variable cost curve diverge is given by $t_{pm} = 1 - t_{am} = (Q - K)/Q$. That is, when the proportion of afternoon arriving parcels, $(1 - t)$, is less than the ratio of van capacity to total volume, i.e., $t \geq t_{pm}$, Congo's afternoon variable costs are just equal to the per unit variable cost of van operation times the number of parcels. On the other hand, when the proportion of afternoon arriving parcels exceeds the ratio of van capacity to total output (i.e., $t \leq t_{pm}$), Congo fully utilizes its K units of available van capacity, incurring variable costs of bK. It is then forced to utilize the per piece option for the remaining $(1 - t)Q - K$ afternoon parcels, thereby incurring additional afternoon variable costs of $m[(1 - t)Q - K]$.

It will prove convenient to carry out the subsequent analysis in terms of $z \equiv K/Q$, Congo's *van capacity coverage ratio*. This measures the proportion of the day's total parcel volume that could, if necessary, be delivered by the available van capacity during either the morning or afternoon sub periods. The above expressions can then be rewritten somewhat more concisely as:

$$(3) \qquad V_{am}(t,Q,z) = \begin{cases} btQ: & t \leq z \\ bzQ + mQ(t-z): & t \geq z \end{cases}$$

$$(4) \qquad V_{pm}(t,Q,z) = \begin{cases} b(1-t)Q: & 1-t \leq z \Longrightarrow t \geq 1-z \\ bzQ + mQ[(1-t)-z]: & 1-t \geq z \Longrightarrow t \leq 1-z \end{cases}$$

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The decision facing Congo is to choose its van capacity *K*. For given *Q*, this is equivalent to choosing its van capacity coverage ratio *z*. Because this decision must be made before the timing of the day's parcel arrivals is known, it is natural to assume that Congo seeks to minimize the *expected* costs of its operations. Its expected costs have three components. The first, which is known with certainty, is the amount spent on van capacity $BK = BzQ$. The other components are the *expected* morning and afternoon variable costs. Equations (3) and (4) express these variable costs as a function of any particular realization *t* of the intra day distribution of parcels. To complete the characterization of Congo's choice of van capacity, it is necessary to derive formulae for the expected values of Congo's morning and afternoon variable costs. This is done by *integrating* equations (3) and (4) using the probability density function $f(t)$.

Congo's expected variable costs during the morning sub period, $EV_{am}(Q,z)$, are given by:

(5) $$EV_{am}(Q,z) = \int_0^1 V_{am}(t,Q,z)f(t)dt = bQ\int_0^z tf(t)dt + Q\int_z^1 [bz + m(t-z)]f(t)dt$$

The bifurcated nature of V_{am} reflected in equation (3) is easily dealt with through integration. The first term on the right hand side of equation (5) measures the expected morning variable costs for all of those realizations of *t* such that total morning volume is less than or equal to available van capacity (i.e., $t \leq z$). The second term measures the expected morning variable costs for all of those realizations of *t* which require the use of the per piece option.

Similarly, Congo's expected variable costs during the afternoon sub period, $EV_{pm}(Q,z)$, are given by:

(6) $$EV_{pm}(Q,z) = \int_0^1 V_{pm}(t,Q,z)f(t)dt$$

$$= Q\int_0^{1-z}[bz + m[(1-t) - z]]f(t)dt + bQ\int_{1-z}^{1}(1-t)f(t)dt$$

In this case, available van capacity will be adequate for large realizations of t: i.e., for small afternoon parcel volumes. That is, for all values of $t \geq t_{pm}$. The expected variable costs for those cases are measured by the second integral in equation (6). For large realized afternoon parcel volumes (i.e., $t \leq t_{pm}$), the first integral in equation (6) measures the expected afternoon variable costs when the per piece option must also be employed.

As we shall see, it is important to determine how these variable costs are affected by a change in Congo's van coverage ratio, z. Differentiating equation (5) with respect to z yields:

(7) $$\frac{\partial EV_{am}(Q,z)}{\partial z} = Q\left\{f(z)[bz - (bz + m(z-z))] - (m-b)\int_z^1 f(t)dt\right\}$$

$$= -Q(m-b)\int_z^1 f(t)dt = -Q(m-b)[1-F(z)] < 0$$

Similarly, differentiating equation (6) with respect to z yields:

(8) $$\frac{\partial EV_{pm}(Q,z)}{\partial z} = Q\left\{f(1-z)[bz - (bz + m(1-(1-z)-z))] - (m-b)\int_0^{1-z} f(t)dt\right\}$$

$$= -Q(m-b)\int_0^{1-z} f(t)dt = -Q(m-b)F(1-z) < 0$$

As one would expect, equations (7) and (8) reveal that an increase in Congo's daily van capacity results in a decrease in the expected variable costs it incurs to deliver a given volume of parcels over the course of the day.

From equation (7), we see that the magnitude of this expected morning variable cost decrease is equal to the product of three terms: the total number of units, Q; the variable cost savings on each unit carried by the added van, $m - b$; and the probability, $1 - F(z)$, that morning parcel volumes will exceed van capacity. Similarly, equation (8) reveals that the magnitude of expected afternoon variable cost saving, again, involves $Q(m - b)$, the product of the total number of units and the variable cost savings per unit. However, in this case, that amount is multiplied by the probability, $F(1 - z)$, that the number of afternoon parcels will exceed van capacity.

Congo's daily *total expected costs*, $EC(Q,z)$, are obtained by adding the amount committed to van rental, BzQ, to the expected variable costs discussed above. Congo is assumed to minimize these total costs by trading off the (certain) expense resulting from an increase in van capacity against the sum of the *expected* delivery cost reductions made possible by that added capacity. The First Order Necessary Conditions ("FONCs") for a non negative solution to this minimization problem are given by:

$$(9) \qquad \frac{\partial EC(Q,z)}{\partial z} = BQ + \frac{\partial EV_{am}(Q,z)}{\partial z} + \frac{\partial EV_{pm}(Q,z)}{\partial z} \geq 0; \qquad z \geq 0; \qquad z\frac{\partial EC(Q,z)}{\partial z} = 0$$

Substituting in the results from equations (7) and (8) yields:

$$(10) \quad \frac{\partial EC(Q,z)}{\partial z} = Q\{B - (m - b)[1 - F(z) + F(1 - z)]\} \geq 0; \qquad z \geq 0; \qquad z\frac{\partial EC(Q,z)}{\partial z} = 0$$

When equation (10) holds with equality, it states that, *at the margin*, the cost of an additional unit of van capacity (B) is equal to the savings in per unit variable costs ($m - b$) multiplied by the sum of the probabilities that that unit will be utilized in the morning and/or afternoon. An *interior solution* in which Congo optimally purchases a strictly positive amount of van capacity requires:

$$(11) \qquad MC \equiv B = (m - b)[1 - F(z) + F(1 - z)] \equiv MS^0(z; b, m)$$

Let $z^0(m,b,B)$ denote the solution to this equation.

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For future reference, it is important to note that equation (10) also reveals the conditions under which delivery prices are so low that Congo (optimally) chooses *not* to acquire any van capacity. This situation arises when the derivative of expected costs with respect to the van coverage ratio is positive when evaluated at $z = 0$. Since, by definition, $F(0)$ equals 0 and $F(1 - 0) = 1$, this will occur when $B > 2(m - b)$. Intuitively, this condition says that the capacity cost (B) of the first unit of van capacity purchased costs more than the variable cost savings it makes possible. In that case, it does not pay to install even the first unit.[8]

2.2 Case 1: Intermediate Post rates: i.e., *m* > *a* > *b*.

It is assumed that the majority of the Postal Service's parcels are delivered once a day along with the letters and flats. For the purpose of simplification, this is expressed in the model as the assumption that the Post can meet Congo's delivery requirements only for parcels arriving in the morning. Therefore, the (minimized) variable cost for afternoon arriving parcels is unchanged. However, in the morning, Congo can use the Post as its per piece option rather than FPS or UX. The formula for morning variable costs in this case is given by

(12)
$$V_{am}^{i}(t,Q,z) = \begin{cases} btQ: & t \le z \\ bzQ + aQ(t-z): & t \ge z \end{cases}$$

Then, the expected morning variable cost can be written as:

(13)
$$EV_{am}^{i}(Q,z) = \int_0^1 V_{am}^{i}(t,Q,z)f(t)dt = bQ\int_0^z tf(t)dt + Q\int_z^1[bz + a(t-z)]f(t)dt$$

The derivative of these expected costs with respect to the van coverage ratio is given by:

8 The marginal variable cost savings curve MS^0 is a decreasing function of z {i.e., $dMS^0/dz = -(m-b)[f(z)+f(1-z)] < 0$} and the marginal cost of capacity is constant (at B). Therefore, if it does not pay to install the first unit of van coverage, it does not pay to install any unit. See also Figure 1, below.

$$(14) \qquad \frac{\partial EV_{am}^{i}(Q,z)}{\partial z} = Q\left\{f(z)\left[bz - \left(bz + a(z-z)\right)\right] - (a-b)\int_{z}^{1} f(t)dt\right\}$$
$$= -Q(a-b)[1-F(z)]$$

As in the Base Case, the analysis proceeds by choosing the van coverage ratio to minimize this new expected cost function in which expected variable costs have been reduced by the option of using the Post for morning parcel delivery. That is, expected costs with an intermediate Post price are given by: .$EC^{i}(Q,z) = BQz + EV_{am}^{i} + EV_{pm}$.

The FONCs for a nonnegative solution to the expected cost minimization problem are given by:

$$(15) \qquad \frac{\partial EC^{i}(Q,z)}{\partial z} = BQ + \frac{\partial EV_{am}^{i}(Q,z)}{\partial z} + \frac{\partial EV_{pm}(Q,z)}{\partial z} \geq 0; \qquad z \geq 0; \qquad z\frac{\partial EC^{i}(Q,z)}{\partial z} = 0$$

Using the results of equation (8) and equation (14) yields,

$$(16) \quad \frac{\partial EC^{i}(Q,z)}{\partial z} = Q\{B - (a-b)[1-F(z)] - (m-b)F(1-z)\} \geq 0; z \geq 0; z\frac{\partial EC^{h}(Q,z)}{\partial z} = 0$$

Again recasting this result in marginal terms (for an interior solution), we obtain the condition:

$$(17) \qquad MC \ \equiv B = (a-b)[1-F(z)] + (m-b)F(1-z) \equiv MS^{i}(z;a,b,m)$$

That is, the cost minimizing amount of van coverage is that which equates the marginal van cost to the marginal expected variable cost savings that can be obtained by utilizing both the Post and FPS/UX alternatives. Let z^* denote the (optimal) value of van coverage that satisfies equation (17). Clearly, this optimal value will change as the parameters of the model change. I will often denote the optimal van coverage ratio as $z^*(a,m,b,B)$ to reflect this functional dependence.

Equation (16) can also be used to characterize the delivery rates that are so low as to make it unattractive for Congo to invest in van capacity of its own. An analysis similar to the above reveals that this will be true in Case 1 when $m + a < B + 2b$. Notice that the key condition depends only upon the *sum* of the FPS/UX rate and the Post rate.

2.3 Case 2: Low Post Rates: $m > b > a$.

Again, the assumption that the Post option can be used only for acceptance of morning parcels, means that the afternoon expected variable cost relationships are as in the Base Case. However, the situation in the morning is changed, so that:

(18) $$V_{am}^{l}(t,Q,z) = atQ \quad \forall t \in [0,1]$$

Congo is no longer constrained in the morning by its prearranged van capacity. Any number of parcels that arrive for morning delivery are optimally diverted to the Post.

Proceeding as above, the expected morning variable cost with a low Post access charge can be written as:

(19) $$EV_{am}^{l}(Q,z) = \int_0^1 V_{am}^{l}(t,Q,z)f(t)dt = aQ\int_0^1 tf(t)dt$$

(Notice that these expected costs are not affected by the van coverage ratio.) As in the Base Case, the analysis proceeds by choosing the van coverage ratio to minimize this new expected cost function in which expected variable costs have been reduced by using the Post for all morning parcel deliveries. That is, total expected costs with a low Post price are given by: $EC^{l}(Q,z) = BQz + EV_{am}^{l} + EV_{pm}$. The First Order Necessary Conditions for a nonnegative solution to this minimization problem are given by:

(20) $$\frac{\partial EC^{l}(Q,z)}{\partial z} = BQ + \frac{\partial EV_{pm}(Q,z)}{\partial z} \geq 0; \qquad z \geq 0; \qquad z\frac{\partial EC^{l}(Q,z)}{\partial z} = 0$$

Using equation (8) yields,

(21) $$\frac{\partial EC^{l}(Q,z)}{\partial z} = Q\{B - (m-b)F(1-z)\} \geq 0; \quad z \geq 0; \quad z\frac{\partial EC^{l}(Q,z)}{\partial z} = 0$$

Again, for an interior solution, restating this condition in marginal terms yields:

(22) $$MC \equiv B = (m - b)F(1 - z) \equiv MS^l(z; b, c)$$

That is, the cost minimizing amount of van coverage is that which equates the marginal cost to the marginal variable cost savings that can be obtained by utilizing a low priced FPS alternative in the afternoon. Let $z^l(m,b,B)$ denote the value of the van coverage ratio satisfying equation (22). Similar to the discussions in Cases 0 and 1, equation (21) establishes the conditions under which it is not optimal for Congo to invest in van capacity. That is, given $a < b$, $z^l = 0$ whenever $m < B + b$.

3. Graphical Analysis of Congo's Dispatch Choice

It is perhaps useful to recast the equations of the previous section in terms of a more familiar graphical economic analysis. I begin with the Base Case. The marginal variable cost savings curve, $MS^0(z;b,m)$, is shown in Figure 1.[9] It is a decreasing function of the van coverage ratio z. Examining the term in square brackets on the right hand side of equation (11), we see that marginal variable cost savings are equal to $2(m - b)$ when van coverage is zero and equal to zero when the van coverage is equal to 1 (i.e., when there are enough vans to deliver *all* parcel volume in either period). The optimality condition expressed in equation (11), i.e., the familiar textbook condition that "marginal savings (benefit) equals marginal cost (B)," is satisfied at the van coverage ratio z^0.

9 This curve need not be linear. However, it will be linear when the proportion of morning arriving packages is uniformly distributed between 0 and 1; i.e., when $f(t) = 1$.

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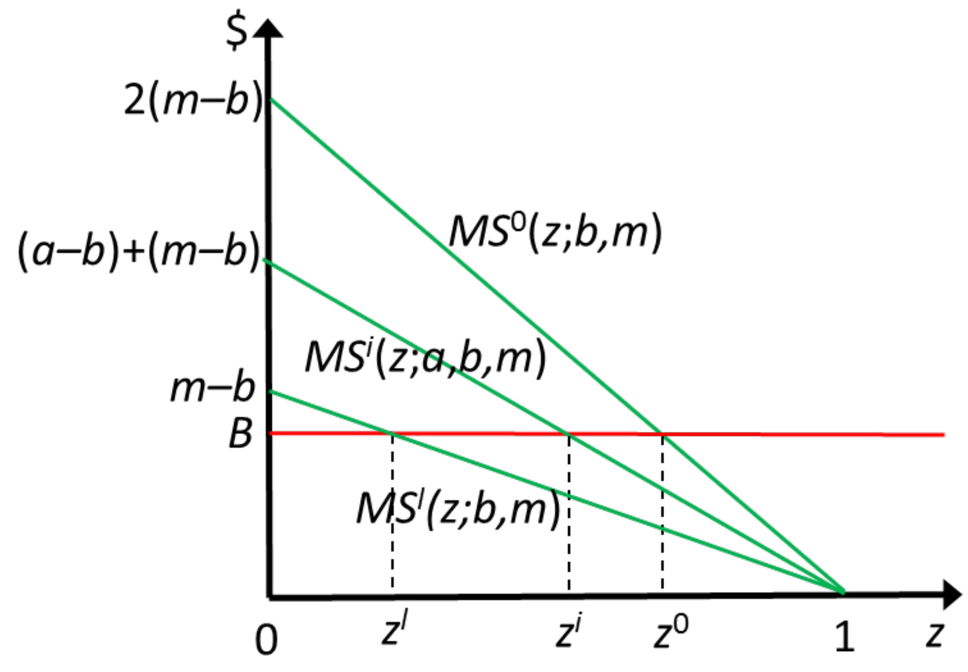

FIGURE 1

The case of an intermediate access price, $a \in (b,m)$, can be analyzed similarly. From the term in square brackets on the right hand side of equation (17), we see that marginal variable cost savings are equal to $(a - b) + (m - b)$ when van coverage is zero and equal to zero when van coverage is equal to 1. This relationship is depicted as the curve MS^i in Figure 1. The optimality condition expressed in equation (17) is now satisfied at the van coverage ratio of $z^i = z^*(a,m,b,B)$. Finally, the case of a low Post price, $a < b$, gives rise to the marginal variable cost savings curve MS^l in Figure 1. From the right hand side of equation (22), we see that marginal variable cost savings are equal to $(m - b)$ when van coverage is zero and, yet again, equal to zero when van coverage is equal to 1. The marginal condition in equation (22) is satisfied at the van coverage ratio z^l. The three cases can be unified in terms of the optimal van coverage function,

z^*, defined above. As Figure 1 hopefully makes clear: $z^0 = z^*(a{=}m,m,b,B)$; $z^i = z^*(a,m,b,B)$; and $z^l = z^*(a{=}b,m,b,B)$.

Thus Figure 1 can be used to "trace out" the effects of changes in Congo's optimal van coverage ratio as the price charged by the Post falls from (very slightly) above the FPS delivery price (m) to (very slightly) below the unit variable cost (b) of Congo's van operations. One can interpret these price changes as "rotating" the marginal variable cost savings curve to the left, keeping the curve anchored at its horizontal intercept of $z = 1$. As a is decreased from m to b, the resulting optimal van coverage ratio decreases from z^0 to z^l.

Figure 1 also provides insight into the conditions under which it is optimal for Congo to optimally choose a van coverage ratio of zero. This is most easily seen in Case 1, when $m > a > b$. The vertical intercept of MS^i, the marginal variable cost savings curve, is $a + m - 2b$. Clearly, when this intercept is below B, the marginal cost of van coverage, the optimal choice of van capacity is zero. Thus, $z^i = 0$ when the *sum* of the delivery rates charged by FPS and the Post are sufficiently low: i.e., for $a + m \leq B + 2b$.

The next step in my diagrammatic analysis is to examine the effects of van coverage on the *expected* parcel delivery volumes of the Post, which I will denote by X. The relationship is shown in Figure 2. I begin with the Base Case. As explained above, this case can also be viewed as the outcome when the Post price is "irrelevantly high:" i.e., $a > m$. Because FPS and UX can deliver in *both* the morning and afternoon, Post volumes are always zero under these circumstances, regardless of the realized value of t. However, as soon as a falls even slightly below m, the Post captures *all* of Congo's morning parcel volumes, U_{am}^0, from FPS. When the prices are *equal*, Congo is indifferent with respect how its parcels are routed in the morning. Hence the "flat" portion of the demand curve depicted in Figure 2.

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It is also easy to determine expected Post parcel volumes for very low prices, $a < b$. In that case, the Post receives all of the morning volumes for delivery. Using equation (19), we see that the expected number of morning parcels is given by:

$$X_{max} \equiv Q \int_0^1 tf(t)dt = Qt^* \quad (23)$$

Here, t^* is the *expected* proportion of parcels that arrive in time for morning delivery. Notice that this quantity is not affected by further reductions in the Post's delivery price, a.

For intermediate values of the access price, $a \in (b,m)$, we see from equation (13) that the expected value of parcels delivered by the Post is given by:

$$X = X[z^*(a,c,b,B)] \equiv Q \int_{z^*}^1 [t - z^*]f(t)dt \quad (24)$$

It is important to note that expected Post parcel volumes depend upon the model parameters only indirectly, through their effects on Congo's optimal van coverage ratio. Volumes increase as the optimal van coverage ratio, z^*, decreases. As discussed above, when the sum of parcel delivery prices is sufficiently low (i.e., $a + m \leq B + 2b$), $z^* = 0$. In that case, expected Post demand is also at its maximal level $X_{max} = Qt^*$.

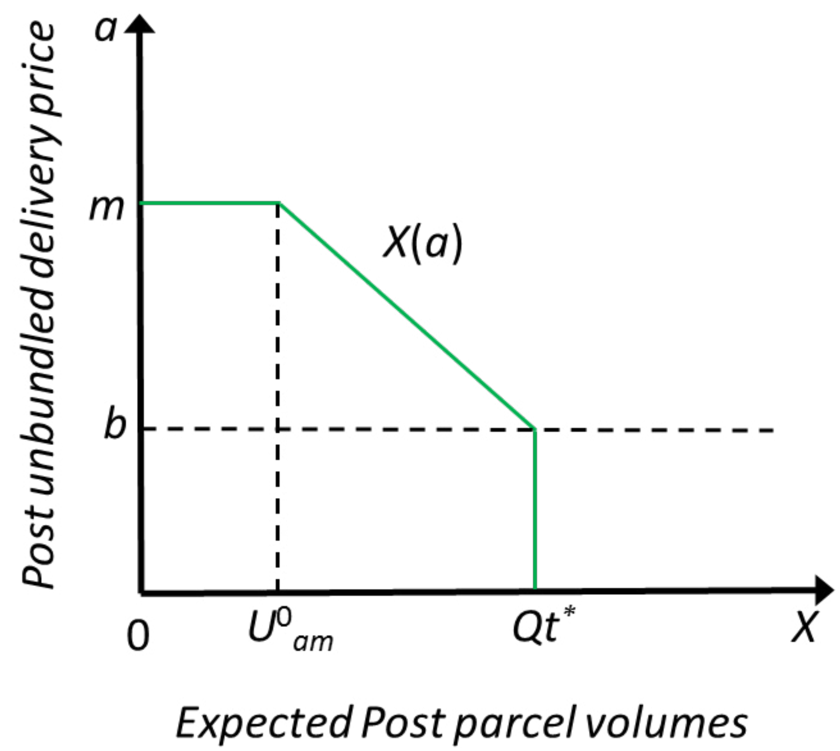

FIGURE 2

Finally, it is interesting to consider the impact of Post access charges on the expected volume of parcels carried by its rivals, FPS and UX. In the Base Case, when the Post rate is non competitive (i.e., $a > m$), the expected number of morning parcels delivered by FPS or UX is given by:

(25) $$U^0_{am} = Q\int_{z^0}^{1}(t - z^0)f(t)dt$$

Intuitively, this integral is the average number of excess parcels that arrive when parcel arrivals in the morning (tQ) exceed van capacity (z^0Q). Similarly, the expected number of parcels delivered by FPS in the afternoon is given by:

(26) $$U^0_{pm} = Q\int_0^{1-z^0}[(1-t) - z^0]f(t)dt$$

The intuitive interpretation, again, is that the integral measures the average number of excess parcels arriving in the afternoon. Adding together the morning and afternoon expected values yields the total expected value of parcels routed through FPS:

(27) $$U^0 = U^0_{am} + U^0_{pm} = Q\int_{z^0}^{1}(t - z^0)f(t)dt + Q\int_0^{1-z^0}[(1-t) - z^0]f(t)dt$$

The situation is somewhat less complicated when the Post rate is at an intermediate level, i.e., between Congo's variable per unit cost and the FPS per piece rate ($m > a > b$). The number of morning parcels routed via FPS falls to zero when $a < m$. The expected number of afternoon parcels routed via FPS is given by:

(28) $$U = U[z^*(a,m,b,B)] = Q\int_0^{1-z^*}[(1-t) - z^*]f(t)dt$$

As before, this expression measures the expected amount by which afternoon parcel volumes exceed available van capacity. In this case, however, the optimal van coverage ratio, z^*, is a function of the Post price (as well as the other parameters of the model). As was true in the case of expected Post parcel volume, the expected amount of parcels carried by FPS or UX depends on the model parameters only through their effects on the optimal van coverage ratio, z^*. Expected FPS/UX parcels decrease as the Post access price increases. This is because the optimal van coverage ratio increases as a increases; which, in turn, leads to a decrease in the expected amount by which the number of afternoon parcels exceeds available van capacity.

For low Post rates ($a < b$), all morning parcels are routed through the Post and, as shown in Figure 1, the optimal van coverage ratio is $z^l = z^*(a{=}b,m,b,B)$. The expected number of excess afternoon parcels routed through FPS or UX is

(29) $$U^l = U[z^*(a = b, m, b, B)] = Q\int_0^{1-z^l}[(1-t) - z^l]f(t)dt$$

This relationship between the expected volume of parcels routed through FPS and the Post's access charge is depicted in the following diagram:

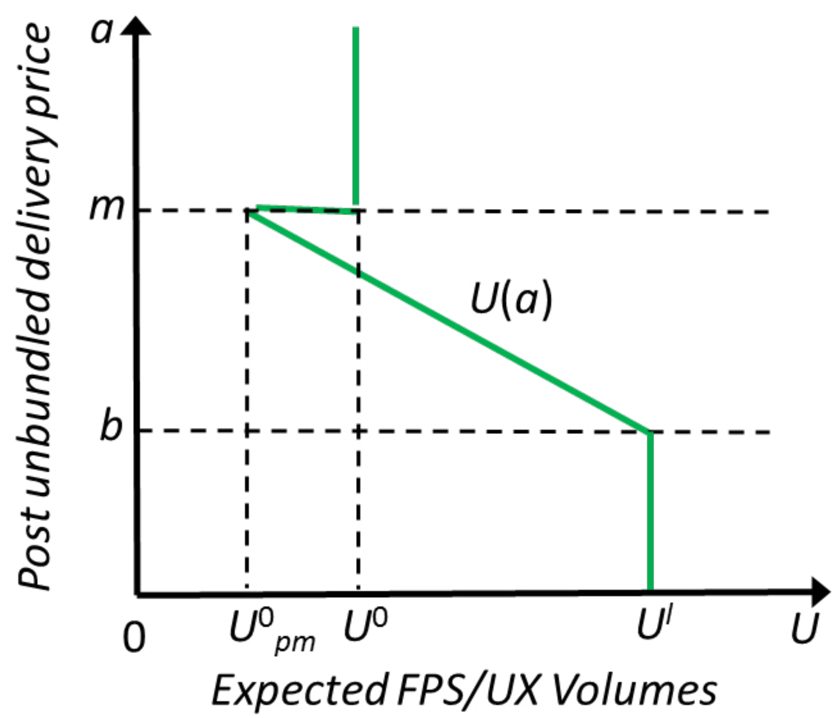

FIGURE 3

For Post rates greater than *m*, the expected volume is constant at $U^0(m)$. When $a = m$ Congo is indifferent between routing it morning parcels via FPS or the Post. However, as soon as *a* drops even slightly below *m*, the morning volumes go to the Post and FPS expected volumes drop discontinuously to $U^0_{pm}(m)$. Further decreases in *a* reduce Congo's optimal van coverage ratio, resulting in an increase in expected FPS afternoon volumes. This increase ceases when *a* drops to slightly below *b*. Intuitively, one might think that routing parcels via FPS or UX and routing parcels via the Post are *substitute* activities from the point of view of Congo. However, it turns out that this is not the case in the current situation. Figure 3 illustrates that, over the competitive range $a \in [b,m)$, the (expected) combined utilization of FPS and UX routing *decreases* (rather than increases) as the price of Post routing increases.

Figure 4 completes the graphical analysis of parcel demand relationships by plotting combined volumes of the parcel carriers as a function of the rate, m, that they charge, holding constant the rate, $a > b$, charged by the Post. For values of $m > a$, the analysis of Case 1 applies, with the Post capturing all of the morning arriving parcels. The demand curve has the traditional downward sloping shape, resulting from the fact that decreases in m reduces the number of Congo vans on the streets.[10] There is a "jump" in the expected volumes of the parcel carriers when m falls from (very, very) slightly above a to (very, very) slightly below a because all of the outsourced morning parcels are shifted to them.[11] For values of $m < a$, the analysis of the Base Case applies. Parcel carrier volumes increase because decreases in m lead to fewer Congo vans on the street. Once m falls to (very, very) slightly below $b + B/2$, Congo takes all of its vans off the street, leaving all Q parcels to be delivered by FPS and UX. Obviously, further decreases in m have no effect on parcel volumes.

10 See the comparative static results derived in Appendix 1.

11 If $m = a$, Congo is indifferent between the Post and FPS/UX options. The volume routed through the parcel carriers can take on any value between U^0_{pm} and U^0, as indicated in Figure 4.

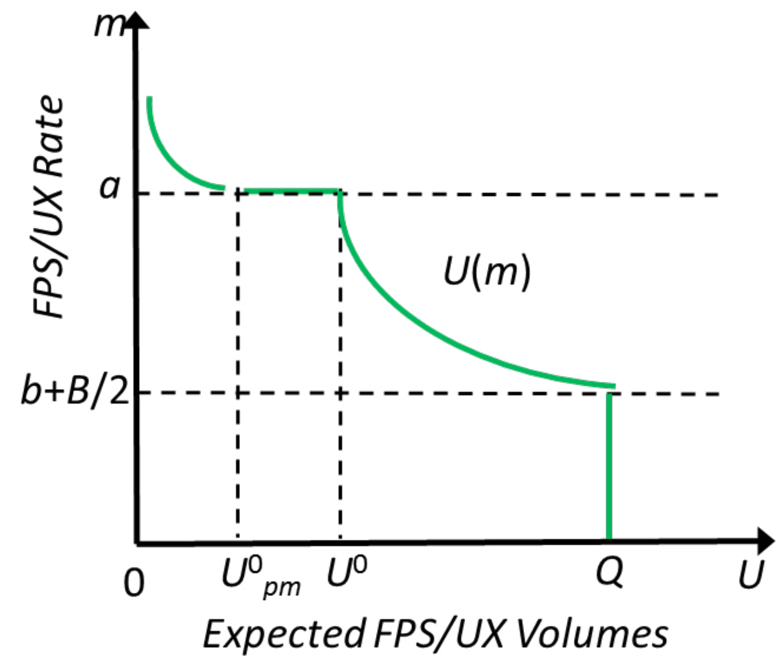

FIGURE 4

The above characterization of the real time dispatching problem of a parcel delivery customer (e.g., Congo) serves as a foundation for the analysis of competition for that customer's business between the Post and a parcel carriers such as FPS and UX. It also provides a framework in which to analyze co-opetition between the Post and FPS or UX. As mentioned above, the situation without unbundled delivery pricing by the Post is equivalent to the case in which the Post charges a (wholesale) delivery price greater than the parcel carriers' per piece delivery rate: i.e., $a > m$. Obviously, in this case, Congo's operations are not affected by the Post's price.

Congo faces a tradeoff between the use of its own van capacity and the purchase of per piece delivery services from FPS and/or UX. Its choice is determined by the relative unit costs of those options and the distribution of parcel arrivals over the day. As equation (11) and Figure 1 make clear, the optimal van coverage ratio in the Base Case, z^0, depends crucially on the ratio of the van's variable cost advantage, $m - b$, to the unit cost, B, of van capacity: i.e., $z^0 = z^0(m,b,B)$. If this ratio is very low, i.e., $(m - b)/B < ½$, vans will not be purchased at all ($z^0 = 0$) because they are too expensive.[12] Conversely, van coverage will always be less than complete, $z^0 < 1$, as long as vans are costly and there is positive probability that *some* parcels will arrive in *both* the morning and afternoon.[13]

The purchase of delivery from the Post by Congo becomes a relevant option when the rate it charges falls below the unit cost of Congo's existing per piece option: i.e., $a < m$. As Figure 2 indicates, expected deliveries by the Post are zero for prices above m. Once the price falls to (slightly below) m, expected Post deliveries "jump" to the Base Case level previously delivered by FPS or UX in the morning. Further decreases in the Post price result in the expected delivery volume increasing steadily to its maximum level of Qt^*. This volume is obtained when the Post price falls to (slightly below) b, the per unit variable cost of van operation. As Figure 1 reveals, the source of the increase in Post expected sales is the *decrease* in Congo's optimal van coverage ratio as a decreases: i.e., from z^0 to z^l.[14] However, once the van coverage ratio falls to z^l, further decreases in the delivery price charged by the Post have no additional impact on the optimal van coverage ratio. This is because it is optimal for Congo to cease all morning deliveries using its vans once a has decreased to (slightly) below b. Further decreases in a reduce Posts revenues, but do not increase expected delivery volume because the Post is assumed to be unable to successfully deliver afternoon parcels.

12 In terms of Figure 1, this would occur when the horizontal van Marginal Cost curve, B, intersects the vertical axis *above* the vertical intercept of the Marginal Savings curve, MS^0: i.e., when $B > 2(m - b)$.

13 In Figure 1, the intersection between B and MS^0 cannot occur at $\mathbf{z} = 1$ unless $B = 0$.

14 Recall that the MS^h curve in Figure 2 shifts to the left as $\boldsymbol{a}$ (and the curve's vertical intercept) decreases.

4. Competition between the Parcel Carriers and the Post for Congo's Business: General Discussion

The analysis thus far has served to characterize Congo's cost minimizing dispatch choices as a function of the per piece parcel delivery rates a and m charged, respectively, by the Post and the parcel carriers. It is now possible to examine the outcome of targeted competition between these two carriers for Congo's parcel volumes.[15] Before proceeding, it is important to recognize the interesting complications that the introduction of arrival time heterogeneity has introduced into the problem. From Congo's point of view, the morning parcel delivery services of the Post and FPS/UX are perfect substitutes. As a result, the firm charging the lower price gets *all* of the parcels not delivered by Congo's vans in the morning. However, in the afternoon, *all* of the parcels not delivered by Congo's vans are routed via FPS or UX, regardless of those carriers' prices. In an important sense, the Post and FPS/UX are competing more directly with Congo's vans than they are with each other.

Examining equations (24) and (28), the expressions for the expected volumes of the Post and the combined volumes of FPS and UX in the interactive range (i.e., when $m > a > b$), reveal that each firm's demand depends upon the other's price only through its effect on Congo's optimal van coverage ratio, $z^*(a,m,b,B)$. This means that, in the interactive range, the effect of an increase in one firm's price leads to a *decrease* in the other firm's demand. In that range, the delivery products of the Post and its rivals are *complements*, not substitutes, from Congo's point of view![16]

15 I assume that this competition takes place by means of Negotiated Service Agreements (NSAs) so that the Post and the parcel carriers are able to charge Congo delivery only prices that are independent of both E2E prices and the delivery only prices charged to those carriers' other customers.

16 This complementary relationship was also noted in discussion of the graph in Figure 3.

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It is often tricky to analyze competitive outcomes when the services in question are complements. To illustrate the issues, assume for simplicity that the distribution of Congo's parcel arrivals over the day is *symmetric*: i.e., $f(t) = f(1 - t)$ so that $F(1 - t) = 1 - F(t)$ and $t^* = \frac{1}{2}$. Intuitively, this assumption means that, *on average*, one half the parcels will arrive in the morning and one half in the afternoon *and* the probability that the realized proportion will be between, say, 0.3 and 0.4 is exactly the same as the probability that it will be between 0.7 and 0.6. That is, the probability density function is symmetric around its mean of 0.5. When f is symmetric, and parcel rates are in the complementary range ($m > a > b$), Appendix 1 shows that:

(1) The optimal van coverage ratio chosen by Congo, z^*, depends only upon the *sum* of the two parcel rates, $p \equiv a + m$.

(2) The expected volumes of the Post and FPS/UX are always equal.

Begin by considering the situation without the unbundling of delivery access by the Post: i.e., our Base Case. Under symmetry, equation (12) can be solved implicitly for the optimal van coverage ratio:

(30) $$F[z^0(m,b,B)] = 1 - \frac{B}{2(m-b)} \implies z^0(m,b,B) = F^{-1}\left[1 - \frac{B}{2(m-b)}\right]$$

Note that the function F^{-1} is defined only for values between zero and one. Thus equation (30) is valid only for values of $m \leq B/2 + b$. For lower values of the FPS/UX parcel rate, Congo's optimal van coverage ratio is zero.

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4.1 The Result of "Perfect Competition" between FPS and UX in the Absence of the Post

I begin with the situation in which FPS and UX aggressively compete for Congo's parcel volumes. As a benchmark, I analyze the case in which FPS and UX have identical unit parcel delivery costs, denoted by c_F.[17] Since they are assumed to offer identical products from Congo's point of view, the competitive equilibrium market delivery price, will be given by $m^C = c_F$. As noted above, this price is available to Congo for both morning and afternoon arriving parcels.

The substantive issue that arises in this case is whether or not Congo finds it profitable to operate any vans, given the extreme competitive behavior of its suppliers. From equations (10) and (11) and the subsequent discussion, we see that Congo will choose to operate its own vans (i.e., $z^0(m{=}c_{F,}b,B) > 0$) only if $B < 2(c_F - b)$. Otherwise, it will choose to rely entirely on the parcel carriers. Thus, the market outcome in this benchmark case is easy to summarize: (i) as perfect competitors, FPS and UX earn zero economic profits; (ii) Congo operates vans only if it can save money by doing so; and (iii) the outcome is efficient in that it minimizes the total expected costs of the delivering the parcel volume Q in the absence of the Post's participation in the market.

17 The parameter c_F refers to the parcel carriers' unit cost in a single market. However, as was the case with Congo's cost parameters, it is likely that there is substantial market – to – market variation in c_F, with greater unit costs in rural areas than in urban areas. Then, market outcomes are likely to vary regionally as well. Also, the unit cost parameter c_F is the result of network optimization on the part of FPS and UX. Indeed, the real time routing problem facing FPS and UX is probably quite similar to that of Congo. And, like Congo, they might find it desirable to contract with the Post for the last mile routing of some of their parcels. Such co-opetition between the Postal Service and E2E parcel carriers was the subject of my earlier paper, OIG (2016). Appendix 2 discusses how c_F can be derived from the choices of FPX or UX, both with and without co-opetition from the Post.

4.2 The Result of "Perfect Coordination" between FPS and UX in the Absence of the Post

It is assumed that, in the absence of the Post, FPS and UX operate as duopolists. Therefore, it may be unreasonable to assume that they always behave as perfect (Bertrand) competitors. As the Industrial Organization literature has amply demonstrated, market outcomes in such situations can range between the perfectly competitive outcome and the collusive monopoly price.[18] Thus, it is instructive to analyze the Congo parcel market under the assumption that FPS and UX are (somehow) apply to coordinate on the joint profit – maximizing delivery price.[19]

The combined profits of FPS and UX when operating without competition from the Post are given by:

(31) $$E\pi^0_{F/U} = \begin{cases} (m - c_F)U^0[z^0(m)]: & m \geq \frac{B}{2} + b \\ \left(\frac{B}{2} + b - c_F\right)Q: & m \leq \frac{B}{2} + b \end{cases}$$

Note that the upper branch of equation (31) reflects Congo's optimal choice of van coverage ratio for each delivery rate set by the parcel carriers. The lower branch of the equation reflects the fact that further reductions in *m* do not increase combined FPS and UX expected parcel

18 See, for example, Carlton and Perloff (2005), Tirole (1989), Viscusi et. al. (2005) and Vives (1999).

19 By focusing on this case, I do not mean to suggest that FPS and UX are in violation of the antitrust statutes. Firms may be able to sustain high price outcomes via so-called *tacit collusion*, which Carlton and Perloff define (p. 785) as "the coordinated actions of firms in an oligopoly despite the lack of an explicit [illegal] cartel agreement."

volumes once $z^0(m) = 0$. Let m^M denote the solution to this profit maximization problem in the Base Case. That is, $m^M = \text{argmax}\{E\pi^0_{F/U}\}$.

Later, I shall make stronger assumptions that allow one to solve explicitly for m^M as a function of the parameters of the model. For the moment, it sufficient to note that m^M will be greater than the competitive rate: i.e., $m^M > c_F$. Note also, that if $m^M \leq B/2 + b$, $z^0(m^M) = 0$ and Congo does not operate any vans. Therefore, even though the price is higher than in the competitive case, there may be no efficiency loss if collusion does not result in Congo "putting vans on the streets." Relative to the competitive outcome, FPS and UX profits go up at Congo's expense, but total delivery costs remain the same. However, inefficiencies will arise if the higher coordinated prices leads to an increase in the number of Congo vans on the street. This is obviously true if $c_F \leq B/2 + b$ but $m^M > B/2 + b$ because collusion results in the efficient outcome of zero Congo vans on the streets being replaced by an inefficient outcome with Congo vans on the streets. Inefficiency also results from collusion when there are (efficiently) Congo vans operating initially. This is because, under competition, Congo's van coverage choice minimizes both the private and social costs of delivery. Relative to the efficient competitive outcome, an increase in the delivery price leads Congo to invest in a socially inefficient increase in van coverage.

4.3 Market Outcomes When Unbundled Delivery Is Also Offered by the Post

Now suppose that the Post wishes to offer Congo a delivery NSA and calculates its initial rate offering *under the assumption that the FPS/UX rate is fixed*. Of course the Post recognizes that it will get no business unless it undercuts the parcel carriers' rate. In the competitive case, that is the end of the matter. The Post must offer a price at least slightly below c_F to obtain any business, and, if it does so, it cannot be undercut by FPS or UX.[20] If, initially, carrier competition was sufficient to keep Congo's vans off the street, i.e., $c_F \leq B/2 + b$, there is no reason for the Post to lower its price further. Matters are somewhat more complicated if Congo found it profitable to operate its own vans under parcel carrier competition. In that case, it may be profitable for the Post to set a rate well below c_F in order to reduce the number of Congo vans on the road. However, determining exactly how much the Post will wish to undercut c_F requires stronger assumptions about the distribution function f.[21] In any case, this lower price cannot be profitably undercut by the parcel carriers.

Analyzing the coordinated case in the presence of competition from the Post is decidedly more complex. Again, in order to obtain any parcels at all, it must undercut m^M, the price charged by the parcel carriers. However, given that it does so, the analysis of Case 1 applies. Under symmetry, Congo's optimal van coverage ratio will depend only upon the sum of a and m. Let c denote the unit delivery cost of the Post. One strategy for the Post is to very, very slightly undercut the FPS/UX price. If it does so, its expected profits will be:

(32) $$E\pi_P = (m^M - c)X[z^*(2m^M)]$$

Things do not end there, however. It is necessary to examine the parcel carriers' reactions to this undercutting on the part of the Post.

20 Of course, this strategy is potentially profitable only if $c < m^0$. If the Post's delivery cost advantage is great enough, it may wish to undercut m^0 *more* than slightly.

21 In the uniform distribution example (i.e., $f(t) = 1$) developed in Section 5, the following results can be derived: (i) The optimal rate for the Post to charge is b as long as there are Congo vans on the street in equilibrium; and (ii) Given that the parcel carriers' are charging c_F, Congo vans will be driven of the street for all Post rates less than or equal to $B + 2b - c_F$. Therefore, the profit maximizing rate for the Post to charge when the parcel carriers are competitive is given by $a^c = max\{b, 2b+B-c_F\}$.

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First, notice that, after the Post has captured the morning arriving half of their business, the parcel carriers can *double* their profits merely by very slightly undercutting the Post rate (which, in turn, was very slightly below m^M). To see this, consider two values of m, one slightly above a and the other slightly below a. Congo's optimal van coverage ratio will be essentially the same at the two prices. This means that the total amount of both morning and afternoon parcels *not* carried by Congo's vans will also be the same. But, when m is slightly less than a, the morning parcels will go to FPS or UX. If m is slightly greater than a, the morning parcels will be routed via the Post. Of course, given this response, the Post will likely rethink its simple undercutting strategy. The next section solves for a Stackleberg Equilibrium of this pricing game for the case in which the proportion of Congo's morning arriving parcels is uniformly distributed between 0 and 1: i.e., $f(t) = 1$.

5. Equilibrium Analysis of Coordinated FPS/UX Pricing with Post Competition and a Uniform Distribution of Parcel Arrivals

The assumptions used in this example are as follows: (i) Congo's morning and afternoon parcel arrival proportions are uniformly distributed: i.e., $f(t) = 1$ and $F(t) = t$; (ii) The Post's unit delivery cost is assumed to be less than the variable (operating) cost of a van, which, in turn, is assumed to be less than the unit costs of FPS and UX: i.e., $c < b < c_F$; and (iii) It is assumed that the per unit van operating cost is greater than the *average* unit costs of the Post and the parcel carriers: i.e., $b > (c + c_F)/2$.

The market outcome I analyze is one in which the Post is the price leader. That is, it is assumed that the Post first chooses a delivery rate *a*. Then, FPS and UX successfully coordinate on the rate $m^R(a)$ that maximizes their joint profits *given* the Post's choice of *a*. Of course, the Post chooses *a* to maximize its profits knowing that the parcel carriers will coordinate on the rate that is their Best Response to its choice.[22]

5.1 Case 1: Vans Are (Relatively) "Inexpensive"

I begin with the case in which vans are relatively inexpensive to purchase or rent (i.e., *B* is "small"), so that Congo's optimal van coverage ratio is positive for all relevant parameter values: i.e., $z^*(a,m,B,b) > 0$. Substitute $f(t) = 1$ into equation (24) to obtain:

(33) $$X = Q\int_{z^*}^{1}[t - z^*]dt = Q\left\{\frac{1-z^{*2}}{2} - z^*(1-z^*)\right\} = \frac{Q}{2}(1-z^*)^2$$

Similarly, upon substituting $f(t) = 1$ into equation (28), we have:

(34) $$U = Q\int_{0}^{1-z^*}[(1-t) - z^*]dt = Q\left\{(1-z^*)^2 - \frac{(1-z^*)^2}{2}\right\} = \frac{Q}{2}(1-z^*)^2$$

Applying the uniformity assumption to equation (A1.6), we see that:

(35) $$F[z^*(a,m,b,B)] = z^*(a,m,b,B) = 1 - \frac{B}{(a-b)+(m-b)}$$

and

(36) $$U = X = \frac{Q}{2}(1-z^*)^2 = \frac{QB^2}{2[(a-b)+(m-b)]^2}$$

Use of the uniform distribution also simplifies the analysis of the non competitive case in which $a > m > b$. Now, equation (11) can be solved to obtain:

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22 This is a price setting Stackelberg oligopoly model. The analysis solves for a subgame perfect Nash equilibrium. See, for example, Tirole (1989) and Vives (1999).

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(37) $$z^0(m,b,B) = 1 - \frac{B}{2(m-b)}$$

Using equation (28), we see that the expected number of parcels routed through FPS and UX is then given by:

(38) $$U^0 = Q(1-z^0)^2 = \frac{QB^2}{4[m-b]^2}$$

Of course, the Post receives no parcels from Congo in this case.

Finally, it will also prove useful to apply the uniform distribution to the case in which the Post chooses a price below the variable cost of operating a van: i.e., $a < b$. In that case, we see from equation (22) that:

(39) $$(1-z^l) = \frac{B}{m-b}$$

Substituting this result into the demand equation for FPS, yields:

(40) $$U^l = \frac{Q}{2}(1-z^l)^2 = \frac{QB^2}{2[m-b]^2}$$

Given that $a < b$, the Post captures all the morning arriving parcels, so its expected parcel demand is given by:

(41) $$X^l = Qt^* = \frac{Q}{2}$$

As a benchmark, I first derive the profit maximizing price that FPS and UX would charge Congo in the absence of delivery competition from the Post. In that case, FPS expected profits would be given by

(42) $$E\pi_F^0 = (m-c_F)U^0[z^0(m)] = (m-c_F)[1-z^0(m)]^2 = \frac{QB^2(m-c_F)}{4(m-b)^2}$$

Differentiating with respect to m yields the following FONCs for the optimal FPS delivery rate:

(43) $$\frac{\partial E\pi_F^0}{\partial m} = \frac{QB^2[(m-b)^2-2(m-c_F)(m-b)]}{4(m-b)^4} = \frac{QB^2[2c_F-m-b]}{4(m-b)^3} = 0$$

Solving the above, we see that the optimal monopoly FPS rate is given by $m^M = 2c_F - b$.

Turning to the case with effective competition from the Post ($m > a > b$), the expected joint profits of FPS and UX are given by

(44) $$E\pi^i_{F/U} = (m - c_F)U[z^*(m,a)] = (m - c_F)[1 - z^*(m)]^2 = \frac{QB^2(m-c_F)}{2[(a-b)+(m-b)]^2}$$

Differentiating with respect to m yields the following FONC for the optimal coordinated delivery rate for the parcel carriers:

(45) $$\frac{\partial E\pi^i_{F/U}}{\partial m} = \frac{QB^2\left[[(a-b)+(m-b)]^2 - 2(m-c_F)[(a-b)+(m-b)]\right]}{4[(a-b)+(m-b)]^4} = \frac{QB^2[2c_F - m + a - 2b]}{4(m-b)^3} = 0$$

Solving the above, we see that the optimal FPS/UX rate in the competitive range depends upon the level of the Post rate and is given by $m^i = a + 2(c_F - b)$.

Finally, consider the joint profits of FPS and UX when the Post sets its rates below the variable cost of Congo van operation: i.e., $a < b$. In that case joint profits are given by:

(46) $$E\pi^l_{F/U} = (m - c_F)U^l[z^l(m)] = (m - c_F)[1 - z^l(m)]^2 = \frac{QB^2(m-c_F)}{2(m-b)^2}$$

Differentiating with respect to m yields the FONC used to determine the optimal coordinated rate with low access pricing by the Post:

(47) $$\frac{\partial E\pi^l_{F/U}}{\partial m} = \frac{QB^2\left[(m-b)^2 - 2(m-c_F)(m-b)\right]}{2(m-b)^4} = \frac{QB^2[2c_F - m - b]}{2(m-b)^3} = 0$$

Solving yields the result that $m^l = 2c_F - b$.

It is now possible to use the above analyses to construct a *Best Response* relationship for the parcel carriers, $m^R(a)$. This specifies the joint profit maximizing parcel rate given any rate, a, charged by the Post. This relationship is depicted by the solid green lines in Figure 4. To develop one's intuition, imagine that the parcel carriers are initially operating in the absence of Post competition. As was shown above, the coordinated, joint profit maximizing rate would then be $m^M = 2c_F - b$. This is indicated by the point M on the 45 degree line in the diagram. Now suppose that the Post were to begin to provide delivery service but charged a price $a > m^0$. Clearly, the Post would not receive any business, and the joint profit maximizing strategy of the parcel carriers would be to continue to charge rate m^0 in response to *any* Post rate $a > m^0$. Thus, $m^R(a)$ is simply a horizontal line for all values of a lying to the right of the 45 degree line $m = a$ in Figure 4.

Now, suppose that the Post adopted a strategy of (very, very) slightly undercutting the initial parcel carrier rate of m^0. Three things would happen: (i) the Post would capture all of the morning arriving parcel volumes not delivered in Congo vans; (ii) the number of vans operated by Congo would remain unchanged (because the *sum* of morning and afternoon parcel rates was essentially unchanged); and (iii) the combined volume and profits of FPS and UX would be cut in half. To determine the parcel carriers' Best Response to this strategy, notice that they can (nearly) recover their profits merely by very slightly undercutting the Post rate (which, in turn, was very slightly below m^0). To see this, consider two values of m, one slightly above a and the other slightly below a. Congo's optimal van coverage ratio will be essentially the same at the two prices. This means that the total amount of both morning and afternoon parcels *not* carried by Congo's vans will also be the same. But, when m is slightly less than a, the morning parcels will go to FPS. If m is slightly greater than a, the morning parcels will be routed via the Post. This argument is valid for any price $a \leq m^0$. As indicated in the diagram, this undercutting argument means that the parcel carriers' Best Response follows the 45 degree line between M and D.

Parcel Carriers' Best Responses when *B* is "small"

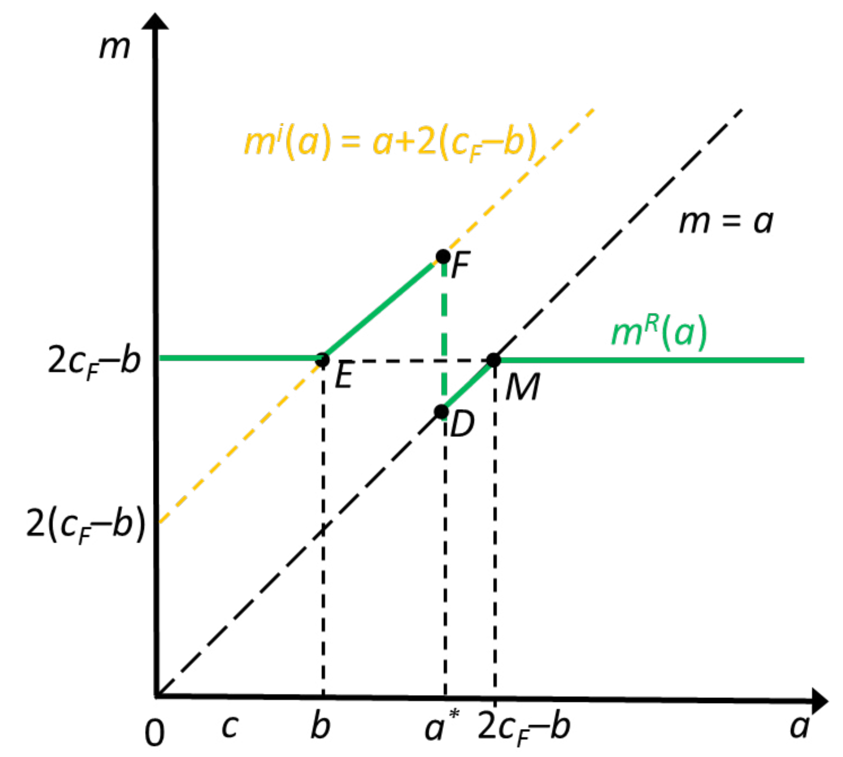

FIGURE 5

What happens at point *D*, where the Post rate equals a^*? Intuitively, the undercutting strategy ensures that the parcel carriers capture *all* of the parcels not carried by Congo's vans. But, since the Post cannot deliver afternoon arriving parcels, the parcel carriers always have the option of conceding the morning volumes to the Post and raising the coordinated price substantially. They will still retain the afternoon parcel volumes not delivered by Congo's vans. Equation (45) allows us to calculate the *higher* price that will yield the greatest profit: i.e., according to the formula $m^i(a) = a + 2(c_F - b)$. The Post rate a^* is determined by the condition that parcel carriers earn the same joint profits by (very, very) slightly undercutting a^* at point *D* as they do by charging the substantially higher price $m^i(a^*) = a^* + 2(c_F - b)$ at point *F*. More precisely, this point of discontinuity in the parcel carriers' Best Response relation is determined by the condition that:

(48) $$E\pi_{F/U}(a^*, a^*) = E\pi_{F/U}\left(m^i(a^*), a^*\right)$$

Under the assumptions made for this example, it is straightforward to show[23] that

(49) $$a^* = b + (c_F - b)\sqrt{2}$$

Thus, the Best Response relation of the parcel carriers "jumps up" discontinuously at a^*. Expected joint profits are the same at point *D*, where the carriers charge a rate slightly less than a^*, and at point *F*, where they collude on a rate $m^i(a^*) = a^* + 2(c_F - b) = b + (c_F - b)(2 + \sqrt{2}$.

From point *F*, the Best Response relation $m^R(a)$ continues to follow $m^i(a)$, the optimal response derived in equation (45) until point *E* is reached, where $a = b$. To the left of this point, the Best Response of the parcel carriers is determined by $m^l(a)$ instead of $m^i(a)$. The Best Response function, $m^R(a)$, becomes horizontal at the level $2c_F – b = m^l(b) = m^i(b)$. Intuitively, the Best Response of the parcel carriers to Post rates, $m^R(a)$, remains horizontal at $2c_F – b$ until $a = b$ at point E. For higher values of *a*, the parcel carriers set the price that optimally exploits their joint afternoon parcel monopoly (given *a*), until point *F* is reached. There, the parcel carriers are indifferent between colluding on the price an afternoon monopolist would choose and also capturing the morning market by slightly undercutting the Post price. For Post rates to the right of point *D*, the parcel carriers *strictly* prefer to serve all of the parcel volumes outsourced by

---

23 When $f(t)$ =1, $E\pi_F(a^*, a^*) = QB^2\{(a^* - c_F)/4(a^* - b)^2\}$ and $E\pi_F(m^i(a^*), a^*) = QB^2/8(a^* + c_F - 2b)$. Equating the two values and cancelling terms yields: $2(a^* - c_F)(a^* + c_F - 2b) = (a^* - b)^2$. Solving this condition for a^* yields the result in equation (49).

Congo by undercutting any rate set by the Post. However, if the Post where to set a rate higher than the monopoly rate of $m = m^0 = 2c_F - b$, the parcel carriers would have nothing to gain by slightly undercutting the increased rate. By maintaining its rate at m^0, they capture both the afternoon and morning outsourced volumes at the profit maximizing rate. That is, the Best Response relation $m^R(a)$ is horizontal beyond $a = 2c_F - b$.

Having determined the coordinated Best Response of the parcel carriers for any chosen a, the problem facing the Post is to choose that a which maximizes its expected profits, *taking into account the response of the parcel carriers*. More precisely, its problem is to $\max_a E\pi_P[a, m^R(a)]$. Figure 4 shows that there are four segments of the parcel carriers Best Response relation to evaluate. The section to the right of *M* can immediately be eliminated, since it includes only price pairs where a is greater than m. Choosing a rate along this segment would yield the Post zero volume and zero profits. One can rule out rates on the *DM* segment for the same reason. As we have seen, the Best Response of the parcel carriers to any Post rate between a^* and $2c_F - b$ is to undercut it (very, very) slightly. Again, the Post would obtain no parcels or profits.

Turn next to the *EF* segment of the parcel carriers Best Response relation. Here, $m^R(a)$ coincides with $m^i(a) = a + 2(c_F - b)$. We need only consider prices greater than or equal to b because, as shown above, lower prices do not increase the expected parcel volume of the Post. Taking into account the Best Response of the parcel carriers, under a uniform distribution, the expected profits of the Post are given by:

(50) $$E\pi_P = (a-c)X(a, m^R(a)) = \frac{QB^2(a-c)}{2\{a-b+[m^R(a)-b]\}^2} = \frac{QB^2(a-c)}{2\{a-b+a+2(c_F-b)-b\}^2} = \frac{QB^2(a-c)}{8\{a+c_F-2b\}^2}$$

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Differentiating with respect to *a* yields:

(51) $$\frac{\partial E\pi_P(a, m^R(a))}{\partial a} = \frac{QB^2[2c - a + c_F - 2b]}{8[a + c_F - 2b]^3}$$

Evaluating this derivative at the lowest relevant value: i.e., *a* = *b*, we see that

(52) $$\left(\frac{\partial E\pi_P}{\partial a}\right)_{a=b} = \frac{QB^2[2c - a + c_F - 2b]}{8[c_F - b]^3} = \frac{QB^2[(c - b) + (c_F + c - 2b]}{8[c_F - b]^3} < 0$$

The strict inequality follows from the assumptions made at the beginning of the section that the variable costs of operating Congo's vans are (i) greater than the Post's marginal costs (*b* > *c*) and (ii) greater than the average of the marginal costs of the Post and parcel carriers. Since the Post's expected profits are a convex function of *a*, equation (52) establishes that, in the present example, increasing the Post's rate above *b* will *reduce* the Post's expected profits after taking into account the responses of the parcel carriers and Congo. We have already established that the Post's expected profits are higher at *b* than at any lower rate. Therefore, the expected profit maximizing rate for the Post to set in the case of low Congo van costs is *a* = *b* - *e*: i.e., a rate (very, very) slightly below Congo's variable operating costs. This will induce Congo to keep its vans off the street in the morning. What will be the market outcome? The parcel carriers Best Response to this rate is given by $m^R(b) = b + 2(c_F - b) = 2c_F - b$.

The Stackelberg Equilibrium of the pricing rivalry between the parcel carriers and the Post occurs at point *E*, which maximizes the Post's expected profits along the Best Response function of the parcel carriers. There are several interesting features of this equilibrium outcome:

(i) The parcel rate charged by the parcel carriers remains the same as it was before the entry of the Post, at $m^M = m^E = 2c_F - b$.

(ii) The equilibrium Post parcel rate, $a^E = b - e$, is just low enough to induce Congo to idle its vans in the morning.

(iii) Congo's optimal van coverage ratio decreases substantially as a result of Post entry. Because the equilibrium Post price is (very, very) slightly below b, Congo finds itself in Case 2 in the above analysis of its parcel dispatch problem: i.e., equation (22) and Figure 1. Under a uniform distribution, this means that $1 - z^I(m^E) = B/(m - b) = B/2(c_F - \text{b})$. In contrast, we see from equation (37), that in the absence of Post competition, it was initially the case that $(1 - z^0(m^M)) = B/2(m - b) = B/4(c_F - \text{b})$. Thus, as a result of Post competition, Congo chooses to reduce its van coverage ratio from $z^M = 1 - B/4(c_F - b)$ to $z^E = 1 - B/2(c_F - b)$, for a difference of $\Delta z = z^M - z^E = B/4(c_F - b)$.

(iv) The Post takes over morning parcel deliveries, and its expected parcel volume grows from 0 to $X^E = X^I = Qt^* = Q/2$ (with a uniform arrival distribution).

(v) The expected total number of parcels delivered by the parcel carriers increases, despite the loss of all of their morning parcel deliveries to the Post. This is due to the decrease in Congo's van coverage choice which, in turn, results from the complementary roles that the Post and parcel carrier delivery options play in Congo's parcel dispatch problem. Using equation (40), we see that equilibrium expected volumes of the parcel carriers are given by $U^E = U^I(z^i) = B^2Q/2(m^E - b)^2 = B^2Q/8(c_F - b)^2$. Using equation (38), it is straightforward to compare this volume to the initial FPS expected parcel carrier volume at point M, i.e., when the parcel carriers were charging the same price without Post competition: $U^M = U^0(z^0) = B^2Q/4(m^M - b)^2 = B^2Q/16(c_F - b)^2 = U^E/2$.

(vi) Parcel carrier expected profits double as a result of Post delivery of morning arriving parcels. This follows immediately from the facts that: (i) the equilibrium price received

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by the parcel carriers is the same as the coordinated monopoly price; and (iv) their expected volume of parcel deliveries doubled.

(vii) Introduction of unbundled parcel delivery by the Post provides it with a positive profit contribution. In the case a uniform parcel arrival distribution, this contribution equals $(a^E - c)X^i = (b - c)Q/2$.

(viii) Congo's expected total delivery expenditures for any given parcel volume Q are reduced as a result of Post competition.[24]

(ix) This win – win – win result is due to the cost savings that occur as a result of getting many of Congo's relatively inefficient vans off the road.

5.1 Case 2: Congo's Vans Are (Relatively) "Expensive"

The foregoing analysis has dealt with the case of markets in which Congo's van costs are so low relative to the unit costs of FPS and UX, that Congo finds it desirable to operate at least some vans both with and without an unbundled delivery option from the Post. In my view, this is the case of primary interest because it reflects what is currently happening in many markets. It is also of some interest to analyze last mile competition between the Post and FPS/UX in markets in which the outcome does *not* lead to Congo operating any of its own vans. It turns out that

24 In the uniform distribution case, these expected expenditures were initially given by:

$$EC^M = Qz^M B + m^0 U^M + b(Q - U^M) = Q\left\{B\left[1 - \frac{B}{4(m^0 - b)}\right] + b - \frac{B^2}{4(m^0 - b)}\right\} = Q\left\{B + b - \frac{B^2}{4(c_F - b)}\right\}.$$

In the equilibrium after the introduction of Post competition, expected Congo expenditures are:

$$EC^E = Q(b + z^E B) + (m^E - b)U^E + (a^E - b)X^E = Q\left\{b + B\left[1 - \frac{B}{4(c_F - b)}\right] - \frac{B^2}{4(m^0 - b)}\right\} = Q\left\{B + b - \frac{B^2}{2(c_F - b)}\right\}.$$

The reduction in expected Congo expenditures is thus $EC^M - EC^E = QB^2/4(c_F - b)$.

the analysis of this case is somewhat more complicated. Therefore, it is relegated to Appendix 3. Here, I merely state the revised conclusions.

In brief, the impact of unbundled Post entry is not as dramatic when Congo van costs are high or very high. This is because relatively inefficient Congo vans were not operating at the coordinated monopoly price. The effects of Post entry are as follows:

(i) The parcel carriers' coordinated price increases from the original monopoly price of $b + B/2$.

(ii) The equilibrium price charged by the Post "mirrors" that of FPS/UX, keeping the sum of any equilibrium price pair constant at $a + m = B + 2b = 2m^N$.

(iii) Congo's *expected* total expenditure for delivering its Q parcels does not change: it remains at $Q[b + B/2]$. However, Congo expenditures will now fluctuate on a daily basis, being relatively high when the proportion of afternoon arriving parcels is high, and conversely. In the initial situation, Congo's realized costs were the same each day.

(iv) Total *expected* parcel delivery costs decrease by an amount equal to the expected number of morning arriving parcels times the Post morning delivery cost advantage: i.e., $(Q/2)(c_F - c)$.

(v) Given results (iii) and (iv), it is not surprising that the parcel carriers' expected profits fall as a result of Post entry into the morning delivery market.

6. Conclusion

The results of my analysis can be summarized quite succinctly. They all flow directly from my main finding:

This model describes a market in which the Postal Service delivers parcels primarily on letter routes, so that parcels arriving in the afternoon are not delivered until the next day. Under these conditions, an interesting discovery is that the last mile parcel delivery services provided by the Post and its rivals to Congo are complements, not substitutes. In a very real sense, the parcel carriers and the Post are competing primarily with Congo's self-delivery vans, not with each other!

This surprising discovery leads directly to the following results regarding the effects of competition and co-opetition for Congo's business between FPS and the Post:

(i) If competitive behavior by FPS and UX deters Congo from operating vans, the effect of entry by the Post is to efficiently capture morning volumes. The rates paid by Congo remain unchanged and the Post gains profits. (The profits of UX and FPS are unaffected by assumption.)

(ii) If Congo finds it profitable to operate vans in spite of competitive behavior by FPS and UX, entry by the Post results in a win – win outcome. Morning parcels are efficiently shifted to the Post, Congo's delivery costs go down, and the Post gains profits. (The profits of UX and FPS are unaffected by assumption.)

(iii) If, initially, Congo chooses to operate its own vans when FPS and UX coordinate on the monopoly price, Post unbundled entry results in a win – win – win outcome.[25] Congo's costs go down while the profits of the parcel carriers and the Post go up. This surprising result occurs because competition between the Post and its parcel rivals lowers the morning delivery price and reduces the number of vans Congo chooses to operate.

25 As mentioned earlier, I do not mean to suggest that FPS and UX are in violation of the antitrust statutes, but instead may be able to sustain high price outcomes via so called *tacit collusion*.

(iv) (ii) If vans are so expensive that Congo does not operate any vans at the initial coordinated price, Post entry will be profitable and will reduce the profits of the parcel carriers, but it will not change the equilibrium rates paid by Congo.

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Appendices

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Appendix 1: Analysis of Expected Parcel Demand Functions

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The effect of a change in the delivery rate of the parcel carriers on the expected parcel volume of the Post is obtained by differentiating equation (24) with respect to *m*, which yields:

$$\text{(A1.1)} \quad \frac{\partial X}{\partial m} = Q\left\{-\left[z^* - z^*\right]f(z^*)\frac{\partial z^*}{\partial m}\right] - \int_{z^*}^{1}\frac{\partial z^*}{\partial m}f(t)dt\right\} = -Q\frac{\partial z^*}{\partial m}[1 - F(z^*)] < 0.$$

The effect of a change in its own unbundled rate is obtained by differentiating equation (24) with respect to *a*, which yields

$$\text{(A1.2)} \quad \frac{\partial X}{\partial a} = Q\left\{-\left[z^* - z^*\right]f(z^*)\frac{\partial z^*}{\partial a}\right] - \int_{z^*}^{1}\frac{\partial z^*}{\partial a}f(t)dt\right\} = -Q\frac{\partial z^*}{\partial a}[1 - F(z^*)] < 0.$$

Similarly, the effect of an increase in the Post access charge on the expected volumes of the parcel carriers is obtained by differentiating equation (28) with respect to *a*, which yields:

$$\text{(A1.3)} \quad \frac{\partial U}{\partial a} = Q\left\{\left[\left[z^* - z^*\right]f(1 - z^*)\frac{\partial z^*}{\partial a}\right] - \int_{0}^{1-z^*}\frac{\partial z^*}{\partial a}f(t)dt\right\} = -Q\frac{\partial z^*}{\partial a}F(1 - z^*) < 0.$$

And, finally, the effect of an increase in the rate charged by the parcel carriers on their expected volume of parcels is given by:

$$\text{(A1.4)} \quad \frac{\partial U}{\partial m} = Q\left\{\left[\left[z^* - z^*\right]f(1 - z^*)\frac{\partial z^*}{\partial m}\right] - \int_{0}^{1-z^*}\frac{\partial z^*}{\partial m}f(t)dt\right\} = -Q\frac{\partial z^*}{\partial m}F(1 - z^*) < 0.$$

The key comparative statics effects in equations (A1.1) – (A1.4) are that the increases in *m* and/or *a* increase Congo's optimal choice of its van coverage ratio z^*. Intuitively, the fact that both effects are positive follows directly from examining Figure 1. If either *m* or *a* increase, the vertical intercept of the MS^i curve shifts upward. Since its horizontal intercept is unchanged, the intersection of MS^i with must move to the right, increasing z^*.

More formally, the comparative statics effects of interest can be derived using the Implicit Function Theorem. At an interior solution in which $z^* > 0$, equation (19) holds with equality and implicitly defines z^* as a function of the parameters of the model. Differentiating that equation with respect to *a* yields:

$$\text{(A1.5)} \quad \frac{\partial z^*}{\partial a} = -\frac{\frac{\partial^2 EC^i}{\partial z \partial a}}{\frac{\partial^2 EC^i}{\partial z^2}} = -\frac{-[1-F(z^*)]}{(a-b)f(z^*)+(m-b)f(1-z^*)} = \frac{1-F(z^*)}{(a-b)f(z^*)+(m-b)f(1-z^*)} > 0$$

Similarly, differentiating with respect to *m* yields:

$$\text{(A1.6)} \quad \frac{\partial z^*}{\partial m} = -\frac{\frac{\partial^2 EC^i}{\partial z \partial m}}{\frac{\partial^2 EC^i}{\partial z^2}} = -\frac{-F(1-z^*)}{(a-b)f(z^*)+(m-b)f(1-z^*)} = \frac{F(1-z^*)}{(a-b)f(z^*)+(m-b)f(1-z^*)} > 0$$

Substituting these results into equations (A1.1) and (A1.3) yields the result that the cross derivatives of the expected demands for parcel services are equal: i.e.,

$$\text{(A1.7)} \quad \frac{\partial X}{\partial m} = -Q\frac{\partial z^*}{\partial m}[1-F(z^*)] = \frac{-Q[1-F(z^*)]F(1-z^*)}{(a-b)f(z^*)+(m-b)f(1-z^*)} = -Q\frac{\partial z^*}{\partial a}F(1-z^*) = \frac{\partial U}{\partial a}$$

This (standard) symmetry result is due to the fact that both demands are derived from Congo's cost minimizing behavior with respect to its van coverage ratio.

The relationship between the (derived) expected demands for parcel delivery by the Post and the parcel carriers becomes even more interesting if it is assumed that the probability distribution of Congo arrival times between the morning and the afternoon is symmetric: i.e., $f(x) = f(1-x)$ for all $x \in [0,1]$. All such distributions are mirror images around their mean of ½, and their cumulative distribution functions have the property that $[1-F(x)] = F(1-x)$ for all $x \in [0,1]$. Under this symmetry assumption, the Congo's expected demands for Post and FPS parcel delivery are *perfect complements* as long as $a < m$!

To see this, note that under symmetry, the equality version of equation (16) becomes

$$\text{(A1.8)} \quad \frac{\partial EC^i(Q,z)}{\partial z} = Q\{B - [(a-b)+(m-b)][1-F(z)\} = 0$$

This can be rewritten to implicitly define z^* as a function of model parameters:

(A1.9) $F[z^*(a,m,b,B)] = 1 - \frac{B}{(a-b)+(m-b)} \implies z^*(a,m,b,B) = F^{-1}\left[1 - \frac{B}{(a-b)+(m-b)}\right]$

The import of equation (A1.9) is that, when the services are in the complementary range ($a < m$), Congo's optimal van coverage level depends only upon the total $a + m$: i.e., the *sum* of the two delivery rates.

Even more remarkably, when the distribution is symmetric, the expected parcel volumes of FPS and the Post are exactly equal as long as $a > c$! To see this, define the new variable of integration $r = 1 - t$ and $dr = -dt$. Substituting $1 - r$ for t, we can rewrite equation (28) as

(A1.10) $$U(z^*) = Q\int_0^{1-z^*}[(1-t) - z^*]f(t)dt = Q\int_1^{z^*}[r - z^*]f(1-r)d(1-r)$$

By symmetry of the density function, i.e., $f(1 - r) = f(r)$, this becomes:

(A1.11) $$U(z^*) = Q\int_1^{z^*}[r - z^*]f(1-r)d(1-r) = Q\int_{z^*}^1[r - z^*]f(r)dr = X(z^*)$$

Appendix 2: Determining Parcel Carrier Delivery Costs

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In principle, the parcel carriers face a problem quite similar to Congo's in operating their network: i.e., they must arrange for transportation to deliver their parcel volumes while meeting their service standards. I will analyze a simplified version of this problem for an individual parcel carrier; e.g., FPS. I will discuss the solutions both with and without co-opetition with the Post. FPS is assumed to know with substantial accuracy Q_F, the total volume of parcels arriving each day. However it is uncertain about their arrival times over the day. Assume that the proportion, s, arrives in the morning, with the remainder arriving in the afternoon. The probability density function of s, the proportion arriving in the morning, is assumed to be given by $g(s)$, with cumulative distribution function $G(s)$. (For ease of exposition, it is assumed that the distributions of s and t are independent.) FPS purchases van capacity, K_F, at a daily cost of B_F which is available to deliver parcels in both the morning and afternoon. The variable cost of delivering each parcel, regardless of time of day, is assumed to be b_F.

To be sure of meeting its service standards without co-opetition, FPS must hire enough van capacity to deal with the possibility that *all* of its parcels will arrive in either the morning or afternoon: i.e., it must choose $K_F = Q_F$, so that its unavoidable fixed costs are given by $B_F Q_F$. Since the variable costs of delivery are assumed to be the same in each period, the total amount of FPS's variable costs are independent of parcel arrival times. Therefore, its variable costs are given by $b_F Q_F$. Total costs are thus always $b_F + B_F$ per unit.

Now consider the case under co-opetition, in which the Post offers to deliver FPS's *morning arriving* parcels at a delivery access price of $a_F < b_F$. (As above, it is assumed that the Post cannot meet the delivery standards associated with FPS's afternoon arriving parcels.) In this situation, for any morning arrival proportion s, FPS's realized morning variable costs are given by $V^U_{am} = a_U s Q_F$ and its realized afternoon variable costs are given by $V^F_{pm} = b_F(1 - s)Q_F$. After adding its fixed costs of $B_F Q_F$, the expression for FPS's expected total costs is obtained by integrating over s: i.e.,

(A2.1) $$EC^F = B_F Q_F + \int_0^1 \left[V_{am}^F(s) + V_{pm}^F(s)\right] g(s) ds$$

$$= B_F Q_F + Q_F \int^1 [a_F s + b_F(1-s)] g(s) ds = Q_F[B_F + b_F(1-s^*) + a_F s^*]$$

Here, s^* denotes the expected value of the proportion of parcels arriving in the morning.

Equation (A2.1) reveals that co-opetition allows FPS to lower its unit variable costs by diverting its morning arriving parcels to the Post.

Appendix 3: Equilibrium when Congo Vans are “Expensive”

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In this case, it is assumed that the Basic Assumptions of Section 5.1 continue to hold, but I also assume that vans are so expensive that Congo chooses not to purchase them, even in the situation in which the parcel carriers charge a monopoly price. In terms of the present model, this means that the optimal price without Post competition is given by $m^0 = B/2 + b$.[26] In terms of Congo’s van coverage decision (see Figure 1), this is the highest price which would result in $z^0(m^0) = 0$. All Q parcels would be delivered by FPS/UX, regardless of whether they arrived in the morning or afternoon.

In order to analyze the effects of Post entry into (morning) parcel delivery in this case, it is useful to begin by determining the Best Response of the parcel carriers to any morning parcel delivery price a offered by the Post. This process is explained in Figure 6. The diagram is complicated because there are two types of responses that the parcel carriers can make to the introduction of a morning delivery offering of the Post at price a. One option is to simply charge a price less than that of the Post. In that case, Congo will choose not to patronize the Post at all, even in the morning. With identical delivery services, the *best* such price cut response is to merely undercut the Post rate very, very slightly.

26 As shown above, when van costs are “low,” Congo van coverage is strictly positive and the profit maximizing monopoly FPS price is given by $m^0_{low\ B} = 2c_F - b$. In the current case, in which “high” van costs lead to zero van coverage, the profit maximizing FPS monopoly price is given by $m^0_{high\ B} = \frac{B}{2} + b$. As can be seen from Figure 1, the greater is m^0, the greater is z^0. Therefore, it must be the case that $m^0_{high\ B} > m^0_{low\ B}$. Thus, the “high cost” van situation pertains when $B/2 + b \geq 2c_F - b$: i.e., when $B \geq 4(c_F - b)$. For lower values of B, the earlier analysis pertains.

Parcel Carriers' Best Response when *B* is "large"

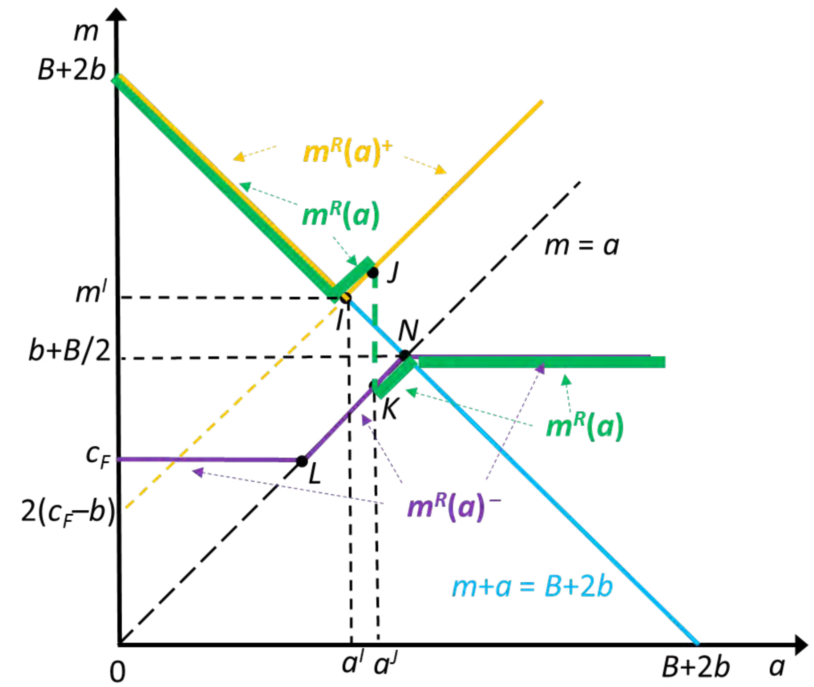

Figure A3 - 1

The purple lines in Figure 6, $m^R(a)^-$, depict the results of this undercutting strategy. The logic behind this outcome is as follows. Suppose the Post attempts to enter the market by offering any rate *greater* than the monopoly rate of $b + B/2$. Clearly, the Post would gain no sales from any such offering and the *Best Response* by the parcel carriers to any Post rate $a > B/2 + b$ would be to leave its monopoly rate unchanged. Thus, one part of the parcel carriers' Best Response curve is just the horizontal line to the right point *N*.

Now suppose the Post quoted a morning delivery rate *a* somewhat lower than the parcel carriers' rate, thereby capturing the entire morning parcel market. Rather than lose the morning market, FPS and UX could seek to recapture their morning parcel delivery market by lowering their rate until it is (very, very) slightly below that of the Post rate: i.e., by setting $m = a - e$. This "undercutting portion" of the parcel carriers' Best Response curve would continue along the diagram's 45 degree line to the left of point N until point L. Here, where $m = c_F$, the parcel carriers will not follow further decreases by the Post since it is better to give up the market rather than price below cost. Thus, for $a \leq c_F$, the undercutting Best Response curve of the parcel carriers is the horizontal line to the left of point L. To summarize, the parcel carriers' undercutting Best Response curve, $m^R(a)^-$, consist of three parts: (i) a horizontal segment from point c_F on the vertical axis to point L on the $m = a$, 45 degree line; (ii) an increasing portion running along the 45 degree line from L to the monopoly point N; and (iii) an additional horizontal segment to the right of point N.

However, the fact that the Post cannot deliver afternoon arriving parcels means that the parcel carriers always have an alternative to the simple undercutting strategy. They can respond to a Post rate offering by charging a significantly *higher* price, thereby focusing their attention on afternoon deliveries not threatened by the Post. Indeed, this type of response was the focus of much of the analysis in the "low van cost" example discussed above. The upward sloping yellow line in Figure 5 replicates the similar green line in Figure 4. In this case, however, this upward sloping portion of $m^R(a)^+$, the FPS/UX high price Best Response curve, is truncated when it reaches point I on the $a + m = B + 2b$ line because, for any values of a and m that sum to less than $B + 2b$, the optimal van coverage chosen by Congo is zero. Therefore, the total expected parcel demand for FPS, UX and the Post remains constant (at quantity Q) for all price combinations below the negatively sloped 45 degree line through point N. For price pairs to the right of the 45 degree line through the origin, FPS and UX deliver all the parcel volumes. For price pairs to the left of that line, where the Post offers a lower price, the expected parcel volumes of the Post and the parcel carriers (combined) are both $Q/2$.

The implication is that it would *never* be desirable for parcel carriers to charge a price that is both *higher* than that of the Post that results in a combined price *below* the expected demand maximizing combined price of $B + 2b$. Thus, the "high price" Best Response curve of TPS, $m^R(a)^+$, consists of two segments. For high Post rates (to the right of the $a + m = B + 2b$ line), the Best Response of the parcel carriers is to respond with an even higher rate, along the solid yellow line through points I and J. This will induce Congo to invest in a positive amount of van coverage, and the analysis is the same as in the low van cost case, above. This portion of the curve is upward sloping, so FPS will respond to decrease in a by decreasing m, and conversely. However, things become quite different should the Post rate be reduced below a^I. The parcel carriers now have nothing to gain by reducing their price below m^I because this will not result in any increase in their expected demand. All that would happen is that FPS and UX would receive less money from the sale of the same (expected) number of units. A better strategy is to respond to any reduction in a by a dollar for dollar *matching* increase in m! By keeping the sum $a + m$ constant at $B + 2b$, the parcel carriers would increase their profits by selling the same number of expected units at a higher price. Thus, for Post prices lower than a^I, the high price Best Response curve of FPS becomes the downward sloping solid yellow line to the left of I.

To finish the construction of the parcel carriers' Best Response function, $m^R(a)$, is to compare, for every value of a, the profits realized by parcel carriers from charging $m^R(a)^-$ to those obtained from charging $m^R(a)^+$. The outcome of this process is summarized by the heavy green line in Figure 6. As noted above, for Post prices greater than the initial monopoly price of $m = B/2 + b$, there is no need for the parcel carriers to change their price since the Post would not obtain any share of the market, even in the morning. Thus, $m^R(a)$ follows the horizontal line to the right of point N. However, for Post prices below $B/2 + b$, the parcel carriers will lose their morning market unless they undercut the Post rate. Initially, the most profitable response is for the parcel carriers to charge a price slightly below a, and its Best Response follows the 45 degree line to the left of point N. However, as the price that must be undercut decreases, the prospect of giving up the morning business and setting a higher price as an afternoon only coordinated monopoly becomes increasingly attractive increasingly attractive.

This turning point is reached when the Post's rate falls to a^J. Here, parcel carrier profits from (very, very) slightly undercutting a^J (thereby capturing the entire market) are equal to those obtained by significantly raising price to point J on the yellow, high price Best Response curve. This substantial price increase will induce Congo to invest in a strictly positive amount of van

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coverage because $a + m$ is now greater than $B + 2b$. Thus, FPS, UX and the Post capture only the afternoon and morning volumes that exceed Congo's van capacity. For further reductions in the Post rate, the parcel carriers respond by decreasing their price as in the low van cost example discussed above. This process continues until the Post price falls to a^I. As explained earlier, it is never optimal for the parcel carriers to allow the sum of the two rates to fall below $B + 2b$. Therefore, their Best Response to Post prices below a^I is to *increase* the price above m^I, following the downward sloping portion of $m(a)^+$ to the left of point *I*.

To summarize, the heavy green parcel carriers' Best Response function has four segments, with a "jump" in between. The optimal response of the parcel carriers to any Post price *above* $B/2 + b$ is just the monopoly rate of $B/2 + b$, indicated by the horizontal line to the right of point *N*. For lower Post rates between *N* and *K*, FPS and UX do best by (very, very) slightly undercutting the Post rate in order to retain the morning delivery market. For Post rates below a^J, it is optimal for them to abandon the morning parcel delivery market to the Post. Instead, they respond by drastically increasing their rates in the afternoon, even though that induces Congo to purchase some vans. Further reductions in the Post rate are met by moving down the upward sloping portion of the $m^R(a)^+$ curve from point *J* to point *I*. However, as explained above, Post rate reductions below a^I are most profitably met by *increases* in m along the downward sloping portion of the $a + m = B + 2b$ curve to the left of point *I*.

This is not the end of the story, however. The alert reader may have wonder how it was determined that the "jump point" in $m^R(a)$ lies to the right of point *I* rather than to the left: i.e., that $a^J > a^I$. Indeed, it can be shown[27] that if Congo van costs are "very high," i.e., $B > 8(c_F - b)$,

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27 All that is required is to show that parcel carrier profits from the undercutting and afternoon – only strategies are precisely equal at a Post rate of a^I. Profits from the afternoon – only strategy at a^I are given by $\pi_F^A = (m^I - c_F)Q/2 = [a^I + c_F - 2b]Q/2$ and its profits from the undercutting strategy are given by $\pi_F^U = (a^I - c_F)Q$. The former exceeds the latter when $a^I < 3c_F - 2b$. But a^I is just the x – axis value of the intersection of the two linear curves: $a + m = B + 2b$ and $m^R(a^+) = a + 2(c_F - b)$. Solving simultaneously yields the result that $a^I = \frac{B}{2} + 2b - c_F$. So the afternoon – only profits are greater than the undercutting profits at a Post price of a^I when $B < 8(c_F - b)$. This means that the jump point must occur to the right of a^I, as in Figure 6. Similarly, if the inequality is reversed, the jump point lies to the left of a^I, as in Figure 6.

the point at which it pays the parcel carriers to switch from a low price, undercutting strategy to a high price, afternoon – only strategy occurs at Post rates *below* a^I. This situation is illustrated in Figure A3 – 2. There, a Post rate of $a^{J'}$ will cause the parcel carriers' Best Response curve to jump up from point K' to point J'. The Best Response curve is somewhat simpler in this case because there is no "up and down zigzag" as there is between points *I* and *J* in Figure A3 – 1.

Carriers' Best Response when *B* is "very large"

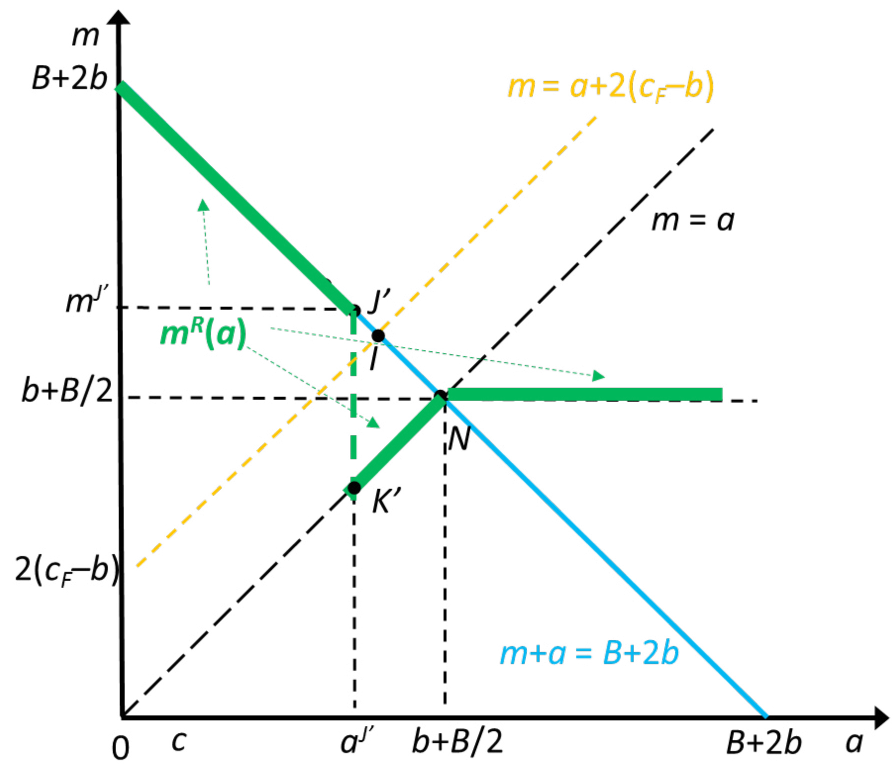

Figure A3 – 2

Having determined the profit maximizing coordinated response of the parcel carriers to any rate offering of the Post, it is straightforward to determine the profit maximizing rate for the Post to set. It's problem is to select the rate, a^S, such that its profits are maximized by the price combination a^S and $m^R(a^S)$: i.e., $a^S = \underset{a}{\operatorname{argmax}} E\pi_P(a^S, m^R(a^S))$. We can eliminate rates that are to the right of point *N* or are between point *N* and points *K* or *K'*. As we have seen, those values of *a* lead to an undercutting response by the parcel carriers, resulting in zero volumes and zero profits for the Post. In addition, we can eliminate those rates along the segment *IJ* in Figure A3 – 1. This is because Post profits decrease as one moves to the right along the curve $m^I(a)$ from point *I*. The argument is similar to that in Section 5.1, above. First, obtain the coordinates of point *I* by simultaneously solving the equations $a^I + m^I = B + 2b$ and $m^I = a^I + 2\ (c_F - b)$. Then evaluate the derivative in equation (51) at the solution point, $a^I = B/2 + 2\text{b} - c_F$, which yields:

$$\left(\frac{\partial E\pi_P}{\partial a}\right)_{a=a^I} = \frac{QB^2[2c - a^I + c_F - 2b]}{8[a^I + c_F - 2b]^3} = -\frac{QB^2[4(2b - c - c_F) + B]}{2B^3} < 0$$

Thus Post profits are higher at point *I* than at any point between *I* and *J*.

This means that we need consider only those points on the $m + a = B + 2b$ line between $a = 0$ and $a = a^J$, in the case of “high” Congo van costs, or $a = a^{J'}$, in the case of “very high” Congo van costs. Because all points on the $m + a = B + 2b$ line result in there being no Congo vans on the street, the Post’s profit maximizing rate is the highest value of *a* that avoids an undercutting response by the parcel carriers: i.e., either a^I or $a^{J'}$.

Appendix 4: Management's Comments

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VICE PRESIDENT, MARKETING

UNITED STATES POSTAL SERVICE

June 2, 2017

CHRISTOPHER BACKLEY
A/DIRECTOR RARC CENTRAL

SUBJECT: Final Review Draft: Play to Win: Competition in Last-Mile Parcel Delivery (RARC-WP-XX-XXX)

As indicated in our discussions on this paper, it is a good analysis with more real-world implications than a typical economic paper because it pertains to four of the largest organizations in America. We agree that there are contingent dependencies that define a package delivery market.

The market is unusual, even unique because a government is competing head-to-head with the private sector and the number one customer has the ability, or at least is fast developing the ability, to bypass its three primary suppliers. That said, Panzar's game-theoretic approach to pricing seems appropriate. The best course of action by all parties will depend on what the other parties decide to do independently.

A few points to consider:

- It probably is a simplification to say that from "Congo's" point of view, the USPS's and UPS/Fed Ex's last-mile services "are complements, not substitutes." Instead, we would suggest that they can be both (depending on the situation).
- The model's assumption of "Congo" having only two choices: use the USPS or UPS/FedEx for delivery, or invest in vans to self-deliver ignores other delivery options. They also have the option to contract with alternative local carriers, such as LaserShip, Uber, and crowdsourcing options. This could allow them to use the USPS "in the morning" and LaserShip "in the afternoon," undermining the argument for a complimentary relationship between USPS morning delivery and UPS/FedEx afternoon delivery.
- The model arguably is based on the exercise of market power (more than one type), and therefore, at least for antitrust reasons, may not hold up in the long run. (The intervention of LaserShip types, which the model does not acknowledge, could militate against the exercise of market power.)

Overall a thought provoking well prepared paper.

Steven W. Monteith

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