A Simplified Analytical Demand Model of Container Dwell Times in Port

This appendix describes the economic foundations of rational decisions with regard to container storage in port terminals and off-dock container yards (ODCYs).

Storage operations can be defined as a subcomponent of an international logistics pathway that starts with loading containers in the supplier’s facilities and ends with unloading them in the customer’s facilities. We define logistics pathway as “a sequential set of logistics operations, warehousing, depot operations, port operations, trucking, and freight forwarding, which deal with the end-to-end movement of freight” (Magala and Sammons 2008). In addition, we focus on containerized trade only, specifically containerized trade through international ports.

When deciding to import a certain quantity of containerized cargo, shippers have to choose either directly or indirectly (through contracted shipping and freight forwarding agents or logistics providers) what logistics pathway to use. This is an informed supply chain decision that is generally based on a combination of rational criteria such as cost, delivery time, frequency, and risk as well as some behavioral patterns (for example, repeat-buyer behaviors).

Our objective is to model how shippers make rational decisions about logistics pathways and, more specifically, what are the drivers of demand
Why Does Cargo Spend Weeks in Sub-Saharan African Ports?

for storage in port terminals or ODCYs. Figure B.1 presents the set of players involved.

By adopting a demand approach, we assume here that importers are the leading decision makers in the selection of the logistics pathway and that they rationally select a logistics pathway based on maximization of their utility.

We construct our demand model by adopting an abstract mode—an abstract commodity—approach that describes freight and storage alternatives by a vector of attributes rather than physical reality (Quandt and Baumol 1969). Likewise, commodities are defined by a set of characteristics such as unit price or packaging and not by the commodity itself.

In the abstract mode approach, two shipping alternatives that share the same attributes relevant to shippers (for example, transit time, cost, level of service) are considered equal. And shippers arguably do not distinguish between two such shipping options because they are generally chosen by carrying and forwarding (C&F) agents and shipping lines with little information along the maritime transport route (for example, survey results confirm shippers have little information about the transshipment hub used for their cargo).

A shipping alternative is therefore specified as a vector $X_i = X_{i1}, X_{i2} \ldots X_{in}$, where the element $X_{ij}$ is the value of the $j$th variable (for example, daily storage cost) characterizing shipping alternative $i$. Likewise, two commodities that share common characteristics (density of value, packaging) can be considered identical from a logistics viewpoint and are referred to using an equivalent vector $Y = Y_{i1}, Y_{i2} \ldots Y_{im}$.

**Figure B.1 Demand System for Container Imports**

Source: Authors.
We start by formulating total logistics costs associated with the selection of a logistics pathway and then construct a deterministic decision-making model based on minimization of these total logistics costs. Next, we look at profits rather than costs and at how profit maximization strategies translate into the selection of a logistics pathway. Then we extend the analysis to a nondeterministic context in which model inputs cannot be precisely estimated ex ante. The nondeterministic model is especially attractive for its ability to explain non-optimality. We finish by offering some concluding remarks and relax, in particular, the assumption of perfect rationality.

**Cost Minimization**

*Total Logistics Cost Formulation in a Scenario of Perfect Certainty*

The logistics pathway depicted in figure B.2 for an international container trade operation consists of the sequence of an export and an import operation. The exporter (supplier) and the importer (customer) are both referred to as “shippers” because they are involved in selecting an international shipping alternative. A large set of international commercial terms (Incoterms) define precisely what is the responsibility of each player. Without loss of generality, we can assume that the typical split of responsibilities is as shown in figure B.2, with some variation for operations in the dotted boxes.

**Figure B.2  Typical Sequence of Operations under the Responsibility of Exporters and Importers for International Container Trade**

<table>
<thead>
<tr>
<th>a. Responsibility of exporters</th>
<th>b. Responsibility of importers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Export</strong></td>
<td><strong>Import</strong></td>
</tr>
<tr>
<td>Initial storage</td>
<td>Loading in port of departure</td>
</tr>
<tr>
<td>Upstream inland transport</td>
<td>Maritime transport</td>
</tr>
<tr>
<td>Loading in port of departure</td>
<td>Unloading in port of destination</td>
</tr>
<tr>
<td>Maritime transport</td>
<td>Port clearance and storage</td>
</tr>
<tr>
<td>Unloading in port of destination</td>
<td>Downstream inland transport</td>
</tr>
<tr>
<td></td>
<td>Final storage</td>
</tr>
</tbody>
</table>

*Source: Authors.*
In this section, we formulate total logistics costs (TLCs) for a standard import operation and model the choice of a logistics pathway by importers as the deterministic output of the minimization of this TLC. We therefore focus only on the sequence of operations described in figure B.2, panel b.

We start by defining a fixed container handling cost, \( r_h \), that encompasses both loading operations in the port of departure and unloading in the port of destination (terminal handling charges, transfer cost).

Maritime transport is defined by two variables: (a) a shipping rate, \( r_m \), and (b) maritime transit time, \( t_m \). The port clearance and storage leg comprises all fees and procedures attached to port clearance and storage in a port or an off-dock container yard before loading on a truck or train for final transport to the customer’s facility. Let us define \( u_p \) as the variable port clearance cost (mainly storage cost, per storage day). Imported containers transiting through a given port of destination generally spend a number of days, \( t_p \), in this port or its dependencies (ODCYs) that is the sum of three components:

\[
\begin{align*}
t_1 &= \text{transfer time (to unload the container from the vessel and transfer it to the yard)} \\
t_2 &= \text{storage time spent in the container terminal or ODCY before loading it onto a truck or train} \\
t_3 &= \text{procedural time (for clearance procedures and controls)}.
\end{align*}
\]

\( t_1 \) is a port attribute that we assume is identical for all shippers and is insignificant with respect to \( t_2 \) and \( t_3 \), while \( t_2 \) and \( t_3 \) are specific attributes depending on both the commodity and the shipper.

We also use other attributes of the commodities:

\[
\begin{align*}
T &= \text{total quantity of commodity } Y \text{ that is imported yearly} \\
V &= \text{unit value of commodity } Y \\
b &= \text{depreciation rate (interest plus obsolescence)} \\
s &= \text{mean interval between reorders (in years)} \\
r_d &= \text{rate for duties and taxes}.
\end{align*}
\]

Whatever the final use of the commodity imported (production input, consumer goods), we consider here that the importer has estimated his total quantity of imports \( T \) for the ongoing year and has opted for some fixed-interval fixed-quantity replenishment strategy. Other
replenishment strategies can be considered later as derived from this simplified case.

We then define the following:

\[ a = \text{cost of ordering and processing a new reorder} \]
\[ d = \text{discount rate} \]
\[ i_p = \text{average inventory level in the port or ODCY storage facility} \]
\[ i_f = \text{average inventory level in the private storage facility} \]

Inland transport is defined by freight rate, \( r_i \), and freight transit time, \( t_i \). Final storage is available at variable cost \( u_p \) with storage time \( t_f \).

Let us then formulate the total logistics cost of our shipper with regard to imports of commodity \( Y \) in the ongoing year:

\[
\text{TLC} = \text{ordering cost} + \text{maritime shipping costs} +
\text{port clearance cost} + \text{inland transport cost} +
\text{final storage cost} + \text{financial cost. (B.1)}
\]

We consider these six terms one at a time:

1. Ordering cost = \( \text{cost per reorder} \times \text{number of reorders} = \frac{a}{s} \)
2. Maritime shipping cost = \( \text{shipping rate} \times \text{total quantity shipped} = r_m T \)
3. Port clearance cost = fixed clearance cost + variable clearance cost, where fixed clearance cost = \( \text{fixed container handling cost} \times \text{amount shipped} = r_h T \) and variable clearance cost = \( \text{cost per unit of time} \times \text{storage time} \times \text{inventory level} = u_p t_f i_p \)
4. Inland transport cost = \( \text{freight rate} \times \text{total quantity shipped} = r_i T \)
5. Final storage cost = \( \text{cost per unit of time} \times \text{storage time} \times \text{inventory level} = u_f t_f i_f \)
6. Financial cost = taxes + depreciation + cost of capital, where taxes = \( \text{rate for taxes and duties} \times \text{unit value} \times \text{amount shipped} = r_d V T \), depreciation cost = \( \text{depreciation rate} \times \text{unit value} \times \text{amount shipped} \times \text{total transit time} = b V T (t_m + t_p + t_i + t_f) \), and cost of capital = \( \text{discount rate} \times \text{total early payment} \times \text{coverage time} \).

Early payment consists of the payment of all taxes, duties, charges, and fees to agents in charge of shipping and clearance operations as soon as cargo exits the port. Coverage time is time between this payment and the effective sale and is thus equal to \( t_f \). We therefore have the following:

\[
\text{Cost of capital} = d t_f (r_m T + r_h T + u_p t_f i_p + r_i T + r_d V T). \quad \text{(B.2)}
\]
We now combine the six elements of the cost function (functions 1–6) to obtain:

\[
TLC = \frac{a}{s} + (1 + dt_f) \left( r_m T + r_h T + u_{p_i} T + r_f T + r_d VT \right) + \frac{uf tf}{f} + bVT \left( t_m + t_p + t_i + t_f \right).
\]  

(B.3)

**Cost Minimization in a Scenario of Perfect Certainty**

In function B.3, there are seven alternative variables for shipping, \( r_m, r_h, t_1, t_m, t_i, u_{p_i}, \) and \( u_f \), and nine commodity- or shipper-specific variables, \( a, s, T, t_2, t_3, t_p, r_d, r_i, \) and \( V \). The two inventory-level variables, \( i_f \) and \( i_p \), are a function of transit time and order quantity.

We now consider different situations that confront shippers, depending on the storage facilities available before final delivery. From a logistical point of view, shippers can be split into two limit cases: shippers who use their private facilities or third-party storage facilities outside the port as their main warehouse and shippers who use the storage services of the port and its dependencies as their primary warehouse. This segmentation is a critical dimension of logistics chains in Africa when it comes to port dwell time in container terminals, and it goes back to the differentiation between “bottleneck-derived terminalization,” in which the port terminal is essentially a source of delay and a capacity constraint in the shippers’ supply chains, and “warehousing-derived terminalization,” in which the terminal replaces warehousing facilities of the shippers and gradually becomes a strategic storage unit (Rodrigue and Notteboom 2009). We show here that this “warehousing-derived terminalization,” together with the cost minimization and profit maximization strategies of shippers, is the main explanation for long dwell times in African ports.

**Shippers without private storage facilities.** We start by looking at the cost minimization behavior of shippers who do not have private storage facilities and who have to leave their cargo in the port storage area until final delivery to clients or production facilities. For those shippers, we have

\[
i_f = 0 \text{ and } t_f = 0.
\]

(B.4)

The only inventory hold is therefore \( i_p \) (inventory in port or ODCY), and in a scenario of perfect certainty average inventory level is

\[
i_p = \frac{T_s}{2}.
\]

(B.5)
Equation B.3 therefore becomes
\[
TLC = \frac{s}{\gamma} + T \left[ r_m + r_h + \frac{1}{2} + u_p t_p + r_i + r_d V + bV \left( t_m + t_p + t_i + t_f \right) \right].
\] (B.6)

Total logistics cost is therefore strictly growing with respect to all time markers \( t_m, t_p, \) and \( t_i, \) and a rational cost-minimization behavior would therefore lead shippers to minimize transit and dwell times.

Shippers now must determine the optimal replenishment interval, \( s. \) Cost minimization with respect to \( s \) leads to
\[
\frac{\partial TLC}{\partial s} = -\frac{a}{s^2} + \frac{u_p t_p T}{2} = 0,
\] (B.7)
so that
\[
s = \sqrt{\frac{2a}{u_p t_p T}}.
\] (B.8)

For example, if we set
- Cost per reorder, \( a = \) US$400 per TEU (20-foot equivalent unit)
- Port storage cost, \( u_p = \) two weeks free time, \( u_p = \) US$20 per day for the next two weeks, and \( u_p = \) US$40 per day thereafter
- \( t_p = 25 \) days
- Annual quantity imported, \( T = 200 \) TEUs,

the optimal interval time \( s \) would be equal to 52 days, and there would be seven reorders per year.

The optimized interval between reorders is inversely proportionate to \( t_p, \) which is the time to perform all physical operations, controls, and procedures in the port. An inefficient port clearance system with very long clearance time would therefore encourage shippers to have shorter replenishment intervals and split their annual orders into smaller and more frequent delivery batches.

**Shipper with private storage facilities.** Let us now consider shippers who possess or have access to some storage facilities outside the port. Assumption B.4 is no longer valid.

As soon as clearance procedures and controls are completed, shippers choose between the two storage options: leaving cargo inside the container terminal or ODCY and clearing it and storing it in their own storage facilities. Let us analyze these two options:
\[
\Delta TLC = \frac{1}{2} T \tau \left( u_f - u_p \right) + T \tau^2 d \left( r_m + r_h + r_i + r_d V \right),
\] (B.9)
where $\tau$ is the additional number of days that the cargo would have to stay in the port in the first option.

The condition for this difference to be negative is therefore

$$\Delta TLC < 0 \Rightarrow u_f < u_p - \frac{2d}{s} (r_m + r_h + r_i + r_d V). \quad (B.10)$$

In other words, if the extra financial cost subsequent to an early clearance of cargo from the port outweighs the potential savings in storage cost, there is no benefit to clearing the cargo from the expensive port storage area and moving it to cheaper storage facilities outside the port.

Despite potential savings in inventory holding costs, shippers might therefore be willing to leave their cargo in the container terminal or ODCY because they cannot pay all of the port clearance charges and fees in advance. Instead, they wait until they have sold the cargo to pay these expenses.

For example, if we set the unit cost per TEU as follows:

- Port storage cost, $u_p = \text{two weeks free time; } u_p = \text{US}\$20 \text{ a day for the next two weeks; } u_p = \text{US}\$40 \text{ a day thereafter}$
- Private storage cost, $u_f = \text{US}\$15 \text{ a day}$
- Shipping rate, $r_m = \text{US}\$1,200$
- Container handling charge, $r_h = \text{US}\$300$
- Freight rate, $r_i = \text{US}\$75$
- Rate for taxes and duties, $r_d = 20\%$
- Discount rate = 12 percent per year (0.032 percent per day)
- Interval between orders, $s = 1/4 \text{ (one order every three months)}$
- Cargo value, $V = \text{US}\$20,000 \text{ per TEU}$,

we get $\frac{2d}{s} (r_m + r_h + r_i + r_d V) = \text{US}\$15$, and condition B.10 would therefore happen only after four weeks. In this scenario, the shipper would leave the container in the port for a full month even if cargo were cleared more quickly.

In reality, we get a very important justification for long dwell times: clearance is cash-eager.

In our example, the shipper would have to pay US\$5,575 in advance to clear his or her cargo from port, which is a significant amount of money that he might not have in hand before concluding the sale. The financial cost for early clearance (US\$15 per TEU) is valued more heavily if the shipper faces cash constraints, as is often the case with imports of commodity products or with new producers, and clearance from port would be even more delayed in such a case. As we see later, many importers
eventually abandon their cargo in the port because they cannot afford these advance payments.

**From Cost Minimization to Profit Maximization**

Our analysis so far has assumed that shippers take logistical decisions by trying to minimize total logistics costs. This is a rational, though partially inaccurate, assumption. It is more accurate to state that shippers take logistical decisions by trying to optimize profits. Now the reality is that, in a perfectly competitive market, prices are exogenous, and the final price of commodity \( Y \) is therefore independent from the logistical decisions of individual shippers. Because profits equal revenues minus costs, optimizing profits equals minimizing costs in these situations.

But if we assume that the price of commodity \( Y \) is affected by the logistical decisions of shippers, we have a different situation. Let us use \( \pi \) to define profits and \( R \) to define revenues. We have revenues equal unit price times total sales:

\[
R = pT, \quad (B.11)
\]

where \( p \) is the unit price of commodity \( Y \).

The price of commodity \( Y \) can be affected at different levels by market conditions and the logistical decisions of shippers. Let us analyze an alternative pricing scenario before coming to any conclusions about the potential outputs of profit maximization strategies.

**Pricing Strategies of Monopolists**

We begin by analyzing which alternative pricing strategies a monopolist can adopt. Monopolies are very particular situations, in which a single firm accounts for the total sales of a given product \( Y \). In such a context, this firm can arbitrarily set the price \( p \) of product \( Y \), and customers will have no choice but to purchase the product at that price or to refuse to purchase it.

A monopolistic position is advantageous because the firm has very strong market power. However, the profit that this firm would make in alternative pricing scenarios also depends on market demand, and despite its power to set the price \( p \) at any desired level, the firm cannot force customers to purchase the product.

If we have a smooth demand function \( D \) as in figure B.3, for any given annual level of output \( T_e \), we can demonstrate that there is a unique
optimal price $p_e$ that would optimize profits of the monopolist firm. This price is the unique solution of the following equation:

$$\frac{\partial \pi}{\partial T} = 0 \lessgtr \frac{\partial R}{\partial T} - \frac{\partial TLC}{\partial T} = 0,$$

which we can also write as $MR = MC$, where $MR$ is the marginal revenue $\partial R/\partial T$ and $MC$ is the marginal cost $\partial TLC/\partial T$.

In this case, the optimal price $p_e$ is higher than the equilibrium price that would be observed in a competitive market and the corresponding annual level of output $T_e$ is lower. In other words, the monopolist sells less, but at a higher price than companies in free competition.

Figure B.3 presents the equilibrium that is reached when a monopolist has U-shape costs and linear demand.

Now let us return to the issue of dwell time. We have demonstrated that, except for some specific cases where port storage is a cheaper option than private storage, longer port dwell time generally translates into higher total logistics costs. Higher port dwell time in figure B.3 would shift the MC curve upward.

The new equilibrium price that would optimize profits of the monopolist firm would therefore be superior to $p_e$ and the corresponding output level, $T_{e'}$, would be lower. In short, the company facing longer dwell times would sell even fewer units, but at an even higher price. This is evident
in the trade of consumer goods in the countries under consideration (low demand and high prices).

But we can demonstrate analytically that, in general, this results in a net loss for the monopolist company because the higher price does not make up for the lost sales (in figure B.4, the darker $\pi_2$ section is smaller than initial profits $\pi_1$).

Therefore, a rational monopolist that charges the profit-maximizing price will seek to reduce port dwell times to optimize profits. However, other pricing behaviors of monopolist companies seem to contradict this conclusion.

A few traders operating in monopolistic situations, especially in land-locked countries, set their prices such that their profits are not affected by adverse logistics conditions, such as delays in delivery and congestion in ports. They just calculate their total logistics costs for each operation after delivery and apply a constant markup to set the final selling price (cost-plus strategy). These traders seem to be indifferent to longer dwell times because their margins and profits are unaffected and they pass on to their customers any extra logistics costs due to longer dwell time.

However, if we try to project this situation, we reach a different conclusion: higher marginal costs would normally lead to a different monopoly

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**Figure B.4** Translation of Monopoly Equilibrium and Profit Variation in the Scenario of Higher Dwell Time

![Graph showing monetary variables](image)

*Source:* Authors.

*Note:* $AC_1 =$ initial average cost; $AC_2 =$ average cost in the scenario of a higher dwell time; $D =$ demand; $MC_1 =$ initial marginal cost; $MC_2 =$ marginal cost in the scenario of a higher dwell time; $p =$ price; $Q =$ output; $\pi_1 =$ initial profits; $\pi_2 =$ profits in the scenario of a higher dwell time.
equilibrium, with a higher selling price, but also lost sales. If the company manages to keep its total profits unaffected by a price rise, the demand curve will be different from the one depicted in figure B.4.

In this case, we have a situation close to the one depicted in figure B.5, where demand is inelastic to price, at least for reasonable price variations. Very desirable products, such as critical production inputs or indispensable food supplies or drugs, perhaps would be purchased by customers at any price, unless their price reaches unaffordable levels or becomes so high that the customer would bear the consequences of not buying the product. We can represent demand in this context by a vertical line or a kinked curve of the kind shown in figure B.5.

Demand for product $Y$ is normally equal to $T_e$ in this scenario, which would be, for example, the total number of people affected by a given disease every year who absolutely need to purchase medication. However, if the price reaches a superior boundary $p_1$, some of these patients will not be able to afford this medication and will not purchase it. If the price is as cheap as $p_2$, some healthy people will rush to purchase the drug at this competitive price, either to use it or to resell it later. In between these two boundaries, all normal users will be willing to purchase the drug, regardless of the price. The monopolistic traders choose to apply a constant

---

**Figure B.5   Monopoly Equilibrium with a Kinked Demand Curve (Inelastic Demand between Two Price Boundaries $p_1$–$p_2$)**

![Graph showing monopoly equilibrium with kinked demand curve](image)

*Source:* Authors.

*Note:* $AC$ = average cost; $D$ = demand; $MC$ = marginal cost; $MR$ = marginal revenue; $p$ = price; $p_1$ = superior price boundary; $p_2$ = inferior price boundary; $Q$ = output; $T_e$ = annual level of output.
markup to keep their profits unaffected, even in the case of higher total logistic costs.

In figure B.6, the darker $\pi_2$ section is equal to initial profits, $\pi_1$, despite the net increase in average cost. In addition, in this case the cost-plus pricing strategy is not the profit-maximizing strategy (a price of $p_1$ would optimize profits in both cases). But it might be a better strategy in the long term, because charging the maximum price, $p_1$, to all customers willing to pay a price between $p_2$ and $p_1$ might lead to a significant amount of lost sales if market demand evolves toward a continuous demand curve between the two price segments observed. Said differently, the inelastic demand function observed here is very likely to be elastic in the long term, because customers would find substitutes. The monopolistic trader therefore prefers to raise his prices to reflect higher logistics costs but to lower the price when logistics costs fall again. However, it is socially impossible to charge very high prices for necessity goods, and a monopolist would therefore face social unrest and public regulation if he were to raise his prices to the profit-maximizing price in all situations.

The second conclusion is therefore that a monopolist who opts for a cost-plus pricing strategy when demand is inelastic to price will not be affected in the short term by higher logistics costs and will make no effort

**Figure B.6 Translation of Monopoly Equilibrium and Profit Variation in the Scenario of Higher Dwell Time and Cost-Plus Pricing Strategy**

Source: Authors.

*Note: $AC_1$ = initial average cost; $AC_2$ = average cost in the scenario of a higher dwell time; $D$ = demand; $p$ = price; $p_1$ = superior price boundary; $p_2$ = inferior price boundary; $Q$ = output; $\pi_1$ = initial profits; $\pi_2$ = profits in the scenario of a higher dwell time.*
to reduce dwell times in case of occasional congestion or occasional inefficiencies of port operators. Such a scenario is likely to happen for cyclical patterns of demand that are elastic to price only in the long term (food supplies, drugs, equipment).

A third pricing behavior derived from this situation of inelastic demand and observed among monopolistic companies is opportunistic pricing. Such traders use, for example, the pretext of higher logistics costs to increase substantially their selling prices. It is especially the case for category C (traders from landlocked countries) during rainy seasons or port congestion periods. For example, a 10 to 20 percent increase in total logistics costs might translate into a 30 percent increase in price. If we refer back to figure B.6, traders would charge price $p_2$ as soon as any difficulty is noticed in the port or along the transport corridor.

Another example of opportunistic behavior is when shippers prefer leaving their cargo in the port until the price peaks in an upward season. They create an artificial shortage in the local market and delay early deliveries until market prices rise. For example, in a situation similar to the one depicted in figure B.7, deliveries will be postponed for at least six or seven days. This is a very particular situation, where rising costs do not constitute a sufficient incentive to accelerate the clearance of goods because expected profits more than balance the extra costs.

Uncertainty about future profits or market risks generally leads traders to behave on the basis of expected expenses and returns rather than absolute levels. The three pricing strategies just discussed (monopoly equilibrium pricing, cost-plus pricing, and opportunistic pricing) are thus complemented by an analysis of expected profits and costs in the next section.

**Figure B.7** Price Hike in a Shortage Situation

![Graph showing price hike in a shortage situation](image)

*Source: Authors.*
Regulation and market controls such as import quotas, price ceilings and floors, or taxation tools also affect pricing decisions of monopolists.

**Pricing Strategies of Oligopolies**

Oligopolies are situations in which a few firms account for the totality of the sales of product \( Y \). Although economic theory generally leaves the oligopoly situation aside and starts by studying the theoretical aspects of free competition and monopolies, the prevalent competitive context of most market segments, especially in Sub-Saharan African countries, is arguably the oligopolistic context.

In this context, firms cannot neglect the market power of competitors, which is negligible in both the competitive and monopolistic situations. Price is affected by the moves of other firms and is not exogenous, and some competitors have a non-negligible size in relation to the total size of the market, which gives them substantial market power.

This distribution of market power in the hands of a few firms can lead to several typical situations and strategies, and economists generally distinguish between the following ones:

- Cartels
- Leader-followers
- Price war (Bertrand competition)
- Nash equilibria–Cournot competition
- Kinked oligopoly

**Cartels and leader-followers.** Cartels act as a virtual monopolist company: market players agree on prices so that they maximize profits in a consensual manner. In leader-follower situations, a single company, usually the biggest market player, imposes its pricing strategy on the other market players, who avoid any competitive move that would upset the leader. In short, the leader acts as a virtual monopolist, and followers are subject to its pricing strategy. This first two oligopolistic situations therefore lead to situations comparable to the monopolistic situation:

- It is in the general interest of profit-maximizing firms to reduce dwell times.
- In particular situations with inelastic demand, higher costs might have no noticeable impact on profit levels, and traders will be indifferent to higher dwell times.
Opportunistic pricing strategies are used occasionally by traders to charge higher prices and increase their profits, despite longer dwell times and higher logistics costs.

**Price war.** Price war is the particular consequence of a duopolistic or oligopolistic situation where firms refuse to cooperate and favor short-run selfish interests. Firms act as price takers and compete by setting prices simultaneously so that the competitive equilibrium is reached despite the limited number of firms. In this context, companies end up pricing goods at marginal cost, and higher dwell time simply translates into higher marginal costs but does not affect the competitive equilibrium: all companies try to reduce dwell time and logistics costs to optimize profits. This is sometimes observed in the trade of second-hand products such as fabrics, electronics, and cars, where some companies are as efficient in terms of cargo clearance time as the largest companies operating in the market, simply because they are trying to win any marginal competitive advantage over their few competitors.

**Nash equilibrium.** A third interesting situation in which firms try to optimize their profits given the decision of other players leads to what is known as Nash equilibrium. It is the most documented scenario and has been deeply analyzed using the powerful body of knowledge of game theory. There is a large set of possible strategies, including collusion, Cournot pricing, or good-faith behavior, but the most important conclusion for our analysis is that cooperative behaviors are generally preferred because they are most profitable for all players.

We are interested here in possible reactions to rising total logistics costs as a consequence of higher dwell times. We can expect in this context that cooperative pricing strategies will not challenge existing price equilibriums and will lead either to limited price adjustments to outweigh additional costs or to relatively stable prices to avoid the risk of lost sales.

**Kinked oligopoly.** Finally, the interesting kinked demand curve theory also helps to explain why prices are quite stable in oligopolistic situations and why discrete price adjustments are more frequent than continuous variations. The fear of the unpredictable consequences of price changes is instrumental in discouraging the few players to undertake any disequilibrating price move. Short-term variations are seldom envisaged, and there is a threshold phenomenon where all companies keep prices
stable despite variable logistics costs. This is observed in the consumer goods industry, where clients know prices because of advertising, and companies do not risk destabilizing the market even if they face higher logistics costs as a result of port congestion, for example.

**The Issue of Uncertainty and Its Impact on Profits**

In the first section of this appendix, we present a cost-minimization model that leads to alternative strategies of operators who do and do not possess private storage facilities. These strategies explain the behavior of operators who generally intend to minimize the dwell time of their containers in port, except when they face cash constraints or prohibitive financial costs.

To construct the model, we make a very strong assumption that traders have a perfect certainty about market demand and dwell times. We relax this assumption here and address the impact of uncertainty from an inventory management perspective. Uncertainty also affects revenues to a larger extent because of the possible impact on prices and thus revenues. We then address the issue of expected revenues and profits. We show that taking uncertainty into account does not change the dynamics of cost minimization or profit maximization; it actually strengthens the conclusions stated at the start of this appendix.

**Inventory Management and the Issue of Safety Stocks**

We have assumed that transit times and demand forecasts are perfectly predictable. This is a strong assumption that does not match reality. In practice, shippers hold an extra amount of stock, known as safety stock, that both covers risks and helps to prevent a shortage of stock in case of congestion, damage during transit, or unanticipated peak in demand.

There is a large set of inventory management practices, and proper dimensioning of safety stock is a painstaking task, especially for unreliable supply chains. The trade-off is to try and reduce, on the one hand, the level of safety stock to keep inventory costs low, but to have, on the other hand, enough extra stock to buffer against stockouts if actual demand exceeds expected demand, for example.

Let us calculate safety stock for these occurrences first—that is, demand forecast errors. A commonly used safety stock calculation is as follows: Safety stock = service factor × standard deviation of demand × lead time\(^{1/2}\). For example, the service factor is 1.64 at the 95 percent satisfaction level, if we assume normal distribution of errors in demand forecast.
Standard deviation of demand should be estimated using approximated distribution based on empirical values. Let us assume, for example, that yearly demand of commodity $Y$ is well approximated by a Poisson process of parameter $T$. The standard deviation in this case is $T^{1/2}$.

Different formulas are used for dwell time, depending on the shipper’s aversion to risk (maximum lead time, minimum lead time, median value). In this case, we consider that the shipper has no ability to reorder during interval $s$. The maximum lead time in case of shortage is therefore the interval between two replenishments plus total transit time: lead time $= s + t_m + t_p + t_i$.

We, therefore, get the following formula for safety stock, $SL$, corresponding to an error in demand forecasts only:

$$SL = 1.64\sqrt{T\sqrt{s + t_m + t_p + t_i}}.$$ \hspace{1cm} (B.13)

The safety stock corresponding to errors in forecast and uncertainty of transit time is given by a more developed formula:

Safety stock $= \text{service factor} \times (\text{average lead time} \times \text{standard deviation of demand}^2 + \text{standard deviation of lead time}^2 \times \text{average demand})^{1/2}$ \hspace{1cm} (B.14)

The first term corresponds to shortages because of an error in forecast, while the second corresponds to shortages because of an uncertainty in lead times.

If we keep the same assumption of normal distribution of errors and Poisson processes (for both demand and transit times), we get the following:

$$SL = 1.64\sqrt{2T(s + t_m + t_p + t_i)}.$$ \hspace{1cm} (B.15)

If we add the latter expression of safety stock level to the average stock in process $Ts/2$, we get a new average stock level:

$$i = \frac{Ts}{2} + 1.64\sqrt{2T(s + t_m + t_p + t_i)}.$$ \hspace{1cm} (B.16)

For example, if we set

Annual quantity imported, $T = 200$ TEUs
Interval between reorders, $s = 90$ days
Maritime transit time, $t_m = 15$ days
Port dwell time, $t_p = 25$ days
Inland transit time, $t_i = 5$ days,

we get an average stock level $i = 45$ TEUs, decomposed into 25 TEUs of strategic inventory and 20 TEUs of safety stock.

This stock is split between inventory inside the port storage facilities and inventory in private storage facilities. The previous conclusion on the arbitrage between both storage options is still valid: potential savings in inventory holding costs should outweigh financial costs to justify early clearance of cargo from the port.

The new total logistics cost becomes, however, nonlinear in $s$ and is thus no longer solvable analytically. Because the average stock level is more important here than in the simplified case of perfect certainty, the conclusions on the relationship between port dwell time and reorder interval or total cost are still valid:

- A longer dwell time inevitably hampers the supply chain by increasing the immobilization cost, and shippers react by having more frequent deliveries of materials ($s$ diminishes).
- A longer dwell time severely affects total logistics costs because of the additional storage and depreciation costs.

**The Impact of Uncertainty on Revenues and Profits**

We have defined two kinds of uncertainty: uncertainty attached to errors in demand forecasts and uncertainty in delivery times. Both uncertainties adversely affect total logistics costs because they induce higher inventory levels and thus higher storage costs and depreciation costs.

If we look at profit maximization rather than cost minimization alone, both uncertainties have a further impact. Uncertainty attached to delivery times has an impact on revenues if we consider the negative impact of late shipments. In general terms, late shipments induce customer dissatisfaction and the possibility of lost sales (if the customer turns to another supplier or cancels his order) of the kind depicted by the solid line in figure B.8. If shipment arrival is not deterministic but follows some probabilistic distribution, the revenue profile becomes of the kind depicted in the dashed line because of the uncertainty of lead times. There are extra losses due to uncertainty since the customer will turn more rapidly to other sources of supply than in deterministic scenarios, and prices will fall more rapidly in the event of logistics congestion. In conclusion, uncertainty affects both revenues and profits in a negative way.
Uncertainty in demand forecasts also leads to uncertainty in expected revenues due to the direct relation between revenue and sales. With expected values of the demand distribution being lower than the corresponding deterministic demand because of uncertainty, revenues are, in general, lower if there is some risk of errors in forecasts.

Risks attached to any attribute (maritime transit time, dwell time, total sales) of the profit function lead to probabilistic formulations that generally have an adverse impact on absolute profit levels but do not change the strategies of market players. In a comfortable price-setting scenario, experience suggests that market players tend to be overcautious and to “build delay time into their production planning” to prepare for the worst situation. If the container happens to arrive on time, they just delay the shipment until they need it (Wood et al. 2002, 169). This hedging behavior is therefore another justification of why “shippers are biased in favor of utilizing the port facility as much as possible” (UNCTAD 1995).

Notes

1. Typical value for $t_1$ is less than one day, while $t_2$ and $t_3$ have typical values of five to 40 days.

2. In practice, all shippers can be grouped into one of the two categories according to the importance of port and warehouse storage time.
References


