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Modeling The Cost of International Trade in Global Supply Chains

Edgar E Blanco

Principal Research Associate
MIT Center for Transportation & Logistics
Massachusetts Institute of Technology
Cambridge, MA
Email: eblanco@mit.edu

Eva Ponce-Cueto

Associate Professor
Escuela Técnica Superior de Ingenieros
    Industriales
Universidad Politécnica de Madrid, Spain

Visiting Professor
MIT Center for Transportation & Logistics
Massachusetts Institute of Technology
Cambridge, MA
Email: eponce@mit.edu

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Edgar E. Blanco
Principal Research Associate
MIT Center for Transportation & Logistics
Massachusetts Institute of Technology, Cambridge, MA

Eva Ponce-Cueto
Associate Professor
Escuela Técnica Superior de Ingenieros Industriales
Universidad Politécnica de Madrid, Spain

Visiting Professor
MIT Center for Transportation & Logistics
Massachusetts Institute of Technology, Cambridge, MA

1   Introduction

In a global economy, international trade plays an important role of the economic development. This is especially relevant in emerging markets, where trade could contribute significantly to the economic growth of the country. Many studies have pointed out the relationship between logistics performance and the volume of bilateral trade. Limão and Venables (2001) analyze transport costs, Hummels (2001) analyzes transport time and Hausman et al. (2013) evaluate the impact of specific improvements in logistics performance in terms of time, cost and reliability (variability in time) on increased trade.

International Trade ads complexity as goods move across borders where are subject to import and export activities that increase lead times and variability on financial and physical flows (e.g. more documents per trade transaction, more signatures per trade transaction, export clearance, and customs inspection). Also, these global supply chains often involve more actors and agencies that support the trade process such as inspection agencies and custom brokers. Surveys aimed at calculating these costs suggest that they may range from 2% to 15% of the value of traded goods.

This paper provides a general framework to model the impact of international trade of a global supply chain. A cost function is proposed for the buyer, the seller and the upstream suppliers that explicitly refers to the additional elements of international trade. The model is applied to compare the impact of different Incoterms rules (see section 3.2.1) in an International Trade taking into account the total cost of the supply chain

for the main actors, including the buyer (importer) and the seller (exporter).

The paper is organized as follows. Section 2 includes a succinct literature review of relevant papers in global trade management, and more specifically a review of those papers that focus on the total cost in global supply chains. Section 3 defines the global supply chain under study and presents the key events in a global trade. A total global trade function is formulated in Section 4, one function cost for buyers and another for upstream sellers. In section 5 the supply chain costs under various trade scenarios are presented and a numerical example is developed in order to illustrate the applicability of the model. Discussion and conclusion are included in section 6.

2 Literature Review

Allen et al. (1985) define a cost function to quantify the importance of time in transit, including also the reliability of transit time for shippers, receivers and carriers, as an important aspect of this model. The yearly cost function propose by Allen et al. (1985) captures all the relevant elements we also consider in our analytical model (inventory cost, ordering cost, cost of expected excesses and stockout cost), but they did not include the impact of international trade in their model.

Many other researchers have proposed a total function cost in supply chains. For instance, Carter and Ferrin (Carter & Ferrin 1995) proposed a model to capture all costs attributable to the supply chain. They consider three main actors in its supply chain: buyer, seller and carrier and they try to analyze how the cost impacts in each actor of this supply chain. The supply chain consider by Carter and Ferrin (Carter & Ferrin 1995) is not an international supply chain, so the complexity associated to the global supply chains that has an international border between the buyer and the supplier is not explicitly considered in their model.

Another interesting contribution in terms of cost quantification in a supply chain is the model proposed by Larson (Larson, 1988). The total cots function proposed by Larson includes the cost of buying materials, the cost of delivering it, the ordering cost, the holding cost for origin and destination inventory and the holding cost for in-transit inventory. The objective of this model is to find the transportation quantity that minimizes the total cost in the supply chain, the Economic Transportation Quantity (ETQ) in a supply chain that includes the vendor, the carrier and the buyer.

However, this model does not consider the complexity of the international trade.

Cavinato (Cavinato 1992) presents a generic and inter functional total cost model that goes beyond the firm and begins to integrate total cost factors through the supply chain. Is one of the first papers that talk about global competition. He also identifies time as a key factor in competition. He proposes a total cost / value hierarchy model including purchasing, transportation, production, and logistics and he also introduces the concept of value.

Regarding global trade, many academics and supply chain managers recognize the complexity of cross-border trade processes and also the importance of improving these processes (Grainger, 2011; Hausman et al. 2010, Hummels, 2007). According to Hausman et al. (2010) understanding the true costs and operational performances in cross-border trade processes is critical for companies to design their global supply network.

Trade costs as defined by Anderson and Wincoop (2004), include all costs incurred in getting a good to a final user other than the marginal cost of producing the good itself. It includes: Transportation costs, policy barriers (tariff and non-tariff barriers), information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs (wholesale and retail). Hummels and Schaur (2012) also identify factors that affect the cost, such as product fragmentation; demand uncertainty; and absence of key components (due to late arrival or due to quality defects).

Many authors analyze the international trade using gravity model approach (McCallum, 1995; Helliwell, 1998; Clark et al., 2004), but the majority of them do not include transportation cost or transportation times. One relevant study that uses a gravity model that explicitly includes transportation costs, in addition to distance, is the one conducted by Limão and Venables (2001). Regarding transport times, Hummels (2001) was one of the first to explicit account of transport time as distinct from cost. He proposes a model of imports from 200 countries to the United States that includes both distance and shipping time (in days). Using cost (by mode of transport: ocean and air) and shipping time for each bilateral trade flow, he estimates the implicit value of time saved in shipping time (each day in shipping time reduces the probability of trade by 1 percent for all goods and by 1.5 percent for manufactured goods).

Hausman et al. (2010) develop a comprehensive global trade process model, which is an application and extension of the total cost of ownership

concept. They provide a framework for evaluating sourcing costs at a microlevel from an integrative perspective (Ellram 1994) and taking also into account supplier performance for better sourcing decisions (e.g., Cavinato 1992; Ellram and Siferd 1998). They also capture the financial flows involved in cross-border trades, in addition to the information and physical flows contemplate in the reference model for international supply chain developed by the UN/CEFACT/TBG - International Trade Procedures and Business Process Analysis Groups (UN/CEFAT/TFG, 2003). Hausman et al. (2010) model offers a better understanding of the costs involved in a complex trading process, being their main contribution the quantification of business values through investments in Information Technology.

Our paper contributes to the scientific literature by adding and extension of Allen et al. (1985) model, proposing a total function cost for each relevant actor in the global supply chain: one model for the seller firm (exporter), and another one for the buyer firm (importer). Our work also extends the work proposed by Hausman et al. (2010) since, the total function cost proposed in this paper allows comparison of different trade term rules across a variety of supply chains.

3 Trade Costs in Global Supply Chains

Consider a global supply chain as the one depicted in Figure 1. A buyer firm (the importer) purchases products from a seller firm (the exporter) in another country to satisfy the demand of its customers. The seller firm (tier 1 supplier of the buyer firm in the global supply chain) procures components and raw materials from its suppliers (tier 2, 3, ..., m, ..., 1 suppliers of the buyer firm), manufactures or assembles the components into final products that are then shipped to the buyer. This paper focuses in the supply chain cost resulting from international trade between the seller and the buyer firms.
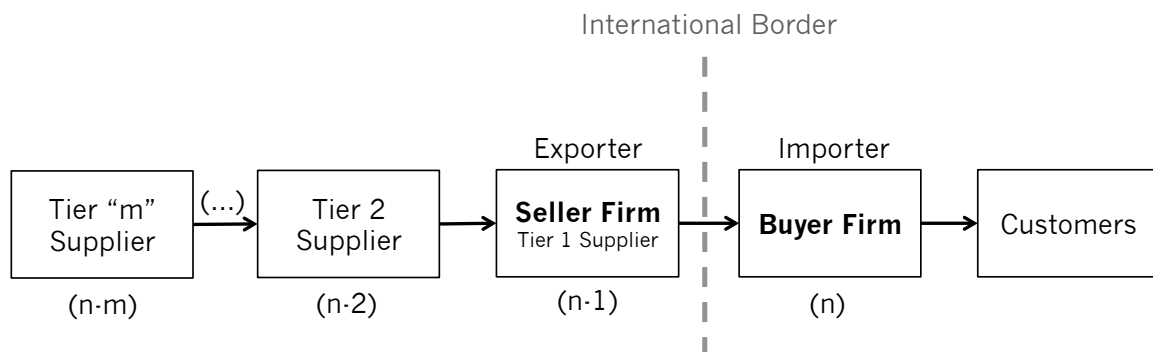

Figure 1. Schematic Global Supply Chain

Figure 2 summarizes the sequence of events of a single international trade between the buyer firm and the seller firm. The buyer firm decides to place and order. The buyer and seller go through a negotiation period until they agree on all the terms (1). The seller then starts manufacturing and/or fulfillment of the order (2). Goods are later ready at the seller facilities ready to be delivered (3). The goods are then prepared for export and arranged directly (or through agents) for all the local transportation (inland) until the port of export (4). All remaining export processes are completed and the goods are transported by the selected carrier(s) until they arrive to the agreed port of import (5). The buyer (or the agreed agents) complete all the required import processes until goods are received at the buyer facilities (6). Milestones (1) through (6) follow the physical flow of goods and their related information flows as needed. However, the trade ends once the seller receives final payment for the goods (PMT). Figure 2 shows payment occurring after final delivery (6), but depending on the negotiation terms, this payment could occur at any point in time between milestones (1) and (6).

There are many more detailed steps (e.g. inspections, clearance, duties) and actors (e.g. customs agencies, freight forwarders) in an international trade (see (Hausman et al. 2010) for an example). The steps selected in Figure 2 capture the key milestones required to understand the physical and monetary flows between buyer and supplier firms that will impact the costs along the supply chain.
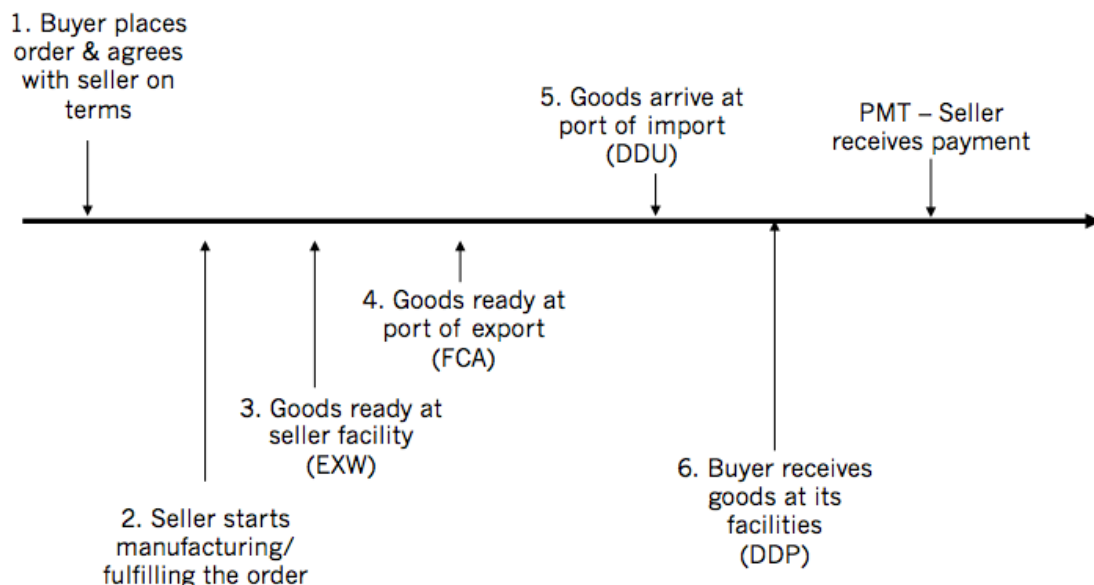

Figure 2. Sequence of events of a single trade

Based on the events of Figure 2, we define $T_{i,j}$ as the elapsed time (in days) from trade event i to trade event j. For example, the following are some relevant lead times:

$T_{1,6}$: buyer lead time between goods receipt at its facilities (6) and order placement (1)

$T_{2,4}$: supplier local fulfillment lead time between goods ready at port for export (4) and manufacturing start (2)

$T_{4,6}$: international trade lead time between buyer receipt of goods (6) and goods ready for export (4). Note that this lead time groups a variety of activities through various agencies involved in the trade process at the international borders such as export clearance, inspection, goods declaration, customs and international transportation transit time among others.

$T_{2,PMT}$: supplier fulfillment-to-cash cycle between goods payment (PMT) and start of order fulfillment (2). This lead time estimates the amount of time the supplier will be tying its capital to satisfy the order terms.

3.1 The Firm Cost Function

Following Allen et al. (1985), the following is a generic yearly cost function for a firm selling a product from its inventory:

$$TC = \underbrace{\frac{Q}{2} \cdot \pi_0 \cdot h_1 + \bar{d} \cdot \bar{T} \cdot \pi_0 \cdot h_2}_{\text{average inventory cost}} + \overbrace{A \cdot \frac{\bar{D}}{Q}}^{\text{ordering cost}} + \underbrace{c_Q \cdot \frac{\bar{D}}{Q}}_{\text{transportation cost}} + \overbrace{\bar{I}_{ss} \cdot \pi_o \cdot h_3}^{\text{safety stock cost}} + \underbrace{\bar{I}_{SO} \cdot \pi_1 \cdot \xi \cdot \frac{\bar{D}}{Q}}_{\text{stock out cost}} \qquad Eq.1$$

where

$\bar{D}$: annual expected demand

$\bar{d}$: daily expected demand (units), equal to $\bar{D}$ /365

π_0: per unit cost (dollars)

π_1 : unit sale price (dollars) equal to $\pi_0 * (1 + \rho)$, where ρ represents the unit margin

Q : the economic order quantity, EOQ (units)

A : ordering cost per order (dollars)

c_Q : transportation cost per order of Q units (dollars)

h_1 : inventory holding cost per year per item (percentage of unit cost)

h_2 : inventory holding cost per year per item in transit (percentage of unit cost)

h_3 : inventory holding cost per excess inventory per year per item (percentage of unit cost)

ξ : stock out cost per unit of items short (percentage of unit sale price)

$\bar{T}$: expected lead time of incoming orders (days)

$\bar{I}_{ss}$: expected inventory safety stock (units)

$\bar{I}_{SO}$: expected stock out units per cycle (units)

σ_d : standard deviation of daily demand (units)

σ_T : standard deviation of lead time of incoming orders (days)

The first two terms capture the average inventory carrying costs assuming the firm owns the goods during the expected lead time. The in transit holding cost, h_2, represents the firm's cost of capital for the money tied up during transportation. The inventory holding cost, h_1, includes h_2 plus any other material handling costs (if applicable). The third term represents the order cost, where $\bar{D}/Q$ is the number of orders per year. The fourth term is the transportation cost expressed as the cost per order times the total number of orders per year.

The fifth and sixth term reflect the costs associated with uncertainty faced by the firm, due to its inability to accurately forecast demand and supplier lead times. The average safety stock, $\bar{I}_{ss}$, is inventory that is maintained in excess throughout the year to provide a service level γ. Assuming that demand and the lead time are normally distributed and independent, $\bar{I}_{ss}$ can be computed as follows:

$$\bar{I}_{SS} = k \cdot \sqrt{\bar{d}^2 \cdot \sigma_T^2 + \bar{T} \cdot \sigma_d^2} \qquad \text{Eq. 2}$$

where k is a scalar value such that the probability of the demand over the lead time being greater than $\bar{d} \cdot \bar{T} + \bar{I}_{ss}$ is less or equal than γ. For highly perishable products, there may be some spoilage or markdowns required to manage the safety stock. Thus the cost of holding this safety stock h_3 may be higher than the holding cost of holding regular cycle inventory h_1. However for most products it is often assumed that $h_3 = h_1$.

Now, with probability $1-\gamma$, the firm will be unable to satisfy the demand within a cycle. $\bar{I}_{SO}$ is the expected number of units the firm will be expected to be out-of-stock each cycle. If the demand is normally distributed, the expected number of units out stock is given by:

$$\bar{I}_{SO} \cdot \sigma_d \cdot [\phi(k) - (1-\gamma) \cdot k] \qquad \text{Eq. 3}$$

where $\phi(k)$ is the density of the standard normal variable of the scalar value k. Now, depending on the type of product, a share of the unfulfilled demand may be back-ordered and satisfied in the next ordering cycle, but the firm's profit may still suffer due to loss of future sales or loss of goodwill. Thus, from the firm perspective, the total lost sales cost will be a percentage ξ of the unit sale price π_1.

It is important to highlight that Eq. 1 assumes that customers buy products from stock and pay cash or the firm faces constant or negligible accounts receivables. For business-to-business supply chains, these assumptions do not hold, specially when international borders are crossed.

3.2 Firm Costs Under International Trade

In a global supply chain that includes trade between a buyer and a seller firm, there are often increased lead times and variability on both the financial and physical flow between the firms due to the complexities of global commerce. In addition, negotiating terms between buyer and seller change dictate which firm bares the various costs of the transaction.

3.2.1 Incoterms

One important aspect in an international contract are the trade terms. Different sets of pre-defined international contract terms (Incoterms) have been published by the International Chamber of Commerce (ICC) since 1936 (Malfliet, 2011). The last set of rules was published in 2010 (ICC 2010). Incoterms 2010 provide harmonized interpretation rules for eleven common trade terms (Malfielt, 2011). When firms agree to Ex Works (EXW) terms the seller makes the goods available at his/her premises, and the buyer incurs the risks for bringing the goods to their final destination. This rule places the maximum obligation to the buyer and the minimum to the seller. At the other extreme is the Delivered Duty Paid (DDP) term, where the seller is responsible for delivering the goods to the named place in the country of the buyer, and pays all costs in bringing the goods to the destination including import duties and taxes. DDP terms places the maximum obligations on the seller who is responsible for all costs, and the minimum obligations on the buyer. Another commonly used term (Hausman et al., 2010; Malfielt, 2011) is the Free Carrier (FCA) where the seller delivers the goods, cleared for export, at a named place (e.g. port of export). The buyer is then responsible for all remaining costs. All of these rules (EXW, FCA, and DDP) can be used for any mode(s) of transport (including multimodal).

Figure 3 illustrates the allocation of costs between buyer and seller of this three Incoterms using the sequence of events of an international trade introduced in Figure 2. Note that Incoterms do not specify who pays for the financial costs (e.g. financing or bank wire fees) of the good payments since these are specified in the private contract between buyer and seller.
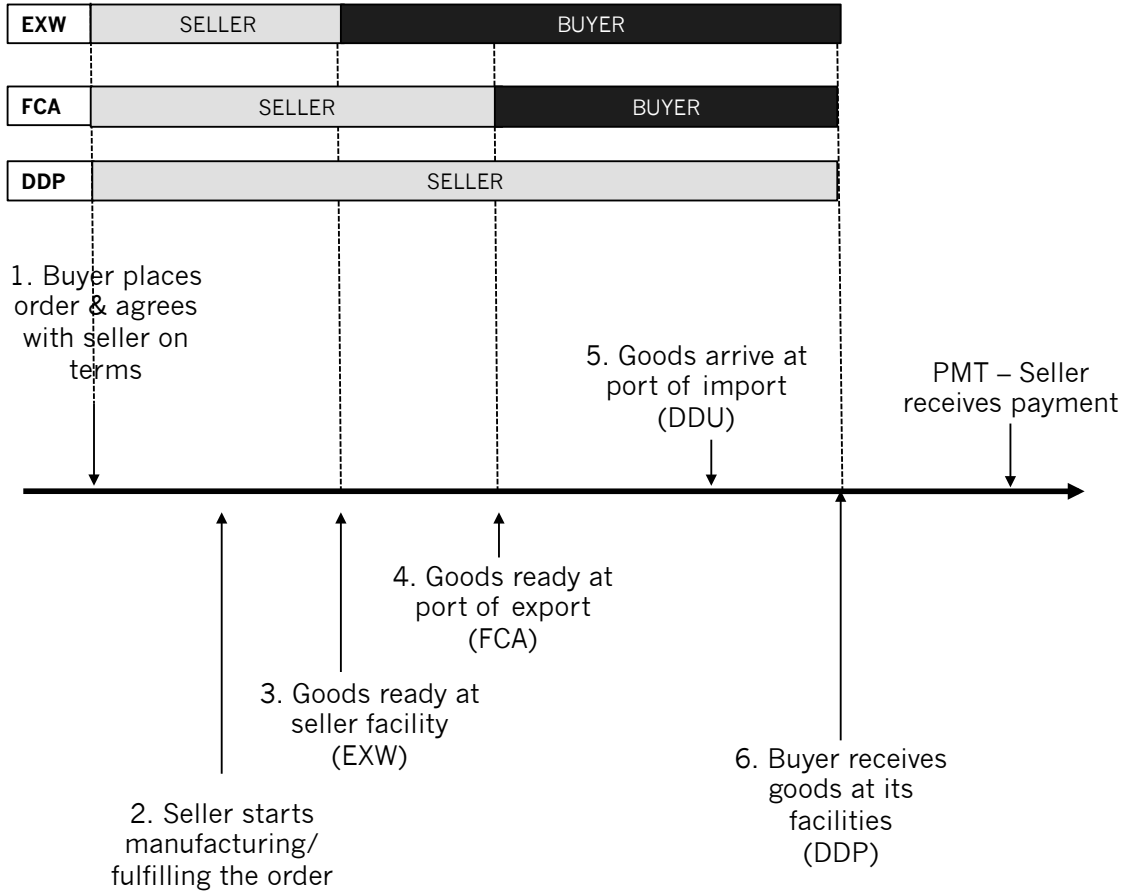
EXW	SELLER	BUYER
FCA	SELLER	BUYER
DDP	SELLER

1. Buyer places order & agrees with seller on terms

5. Goods arrive at port of import (DDU)

PMT – Seller receives payment

4. Goods ready at port of export (FCA)

3. Goods ready at seller facility (EXW)

2. Seller starts manufacturing/ fulfilling the order

6. Buyer receives goods at its facilities (DDP)

Figure 3. Cost allocation between buyer and seller depending on the Incoterm rules

3.2.2 Firm Costs under FCA

To illustrate how international trade affects firm costs in Eq. 1, assume that a buyer firm (importer) has agreed to Free Carrier (FCA) terms at the port of export with the supplier (exporter). Thus, the seller is responsible for all the costs of delivering the goods until event (4) and the buyer will pay all remaining trade costs through event (6). In addition, assume that product-handling costs across the supply chain are negligible, thus only cost of capital is relevant when evaluating inventory costs. The buyer n and seller $n-1$ firm costs will be given by the following equations respectively:

$$TC^n = \frac{Q^n}{2} \cdot \pi_1^{n-1} \cdot r^n + \bar{d} \cdot (\overline{T_{4,6}^n} - \overline{T_{6,PMT}^n}) \cdot \pi_1^{n-1} \cdot r^n + (F^n + A^n) \cdot \frac{\overline{D}}{Q^n} +$$

$$c_{Q^n}^n \cdot \frac{\overline{D}}{Q^n} + \bar{I}_{SS}^n \cdot \pi_1^{n-1} \cdot r^n + \bar{I}_{SO}^n \cdot \pi_1^n \cdot \xi^n \cdot \frac{\overline{D}}{Q^n}$$

Eq. 4

$$TC^{n-1} = \frac{Q^{n-1}}{2} \cdot \pi_1^{n-2} \cdot r^{n-1} + \bar{d} \cdot \overline{T_{3,6}^{n-1}} \cdot \pi_1^{n-2} \cdot r^{n-1} + \bar{d} \cdot \overline{T_{3,PMT}^{n}} \cdot \pi_1^{n-1} \cdot r^{n-1}$$

$$+ A^{n-1} \cdot \frac{\bar{D}}{Q^{n-1}} + F^{n-1} \cdot \frac{\bar{D}}{Q^{n}} + c_{Q^n}^{n-1} \cdot \frac{\bar{D}}{Q^{n}} + c_{Q^{n-1}}^{n-1} \cdot \frac{\bar{D}}{Q^{n-1}}$$

$$+ \bar{I}_{SS}^{n-1} \cdot \pi_1^{n-2} \cdot r^{n-1} + \bar{I}_{SO}^{n-1} \cdot \pi_1^{n-1} \cdot \xi^{n-1} \cdot \frac{\bar{D}}{Q^{n-1}}$$

Eq. 5

In Eq. 4 and Eq. 5, n represents the buyer, $n-1$ represents the seller (tier 1 supplier of buyer firm) and $n-2$ represents the tier 2 supplier of the buyer firm. Since we are assuming that all product-handling costs are negligible then $h_1^n = h_2^n = h_3^n = r^n$, where r^n is the cost of capital for firm n. Note that, the unit cost for firm n, π_0^n will be π_1^{n-1}, the selling price of the upstream firm $n-1$.[*] Since coordinating international trade activities often requires more cost than order products from local suppliers, we define F^n as the additional trade facilitation costs per international order of firm n. For supplier $n-1$ in Eq. 5, this trade facilitation cost is applied per order of quantity Q^n from the buyer, and not to orders of quantity Q^{n-1} placed upstream to the tier 2 supplier which use the regular ordering cost A^{n-1}.

There are other important details in the buyer and seller total costs. First, Eq. 5 assumes that seller is taking ownership of the goods from tier 2 suppliers at their warehouse (i.e. EXW terms) and paying them upon collection and thus is bearing the holding costs for all in transit incoming orders. Thus, $\overline{T_{3,6}^{n-1}} = \overline{T_{PMT,6}^{n-1}}$ and the in transit holding cost for incoming orders will be $\bar{d} \cdot \overline{T_{PMT,6,}^{n-1}} \cdot \pi_1^{n-2} \cdot r^{n-1}$.

Second, the buyer in-transit inventory cost is not a function of the traditional order lead-time ($\bar{T}_{1,6}$) but of the time the buyer has paid for the products while in transit. This is computed as the difference from the time the buyer took possession of the goods (trade event 4) to the moment the goods are received (trade event 6) minus the time it takes the buyer to pay for the goods (trade event PMT) and the moment it took possession of them. In other words, under FCA the cost of capital for in transit goods is $\overline{T_{4,6}^{n}} - \overline{T_{6,PMT}^{n}} = \overline{T_{PMT,6}^{n}}$. Note that if payment is made *after* goods are received (like in Figure 3 where trade event PMT occurs after trade event 6), $\overline{T_{PMT,6}^{n}}$ will be negative and the buyer is effectively offsetting some of its inventory transit costs. On the other hand, the supplier is financing the outbound in transit inventory from the moment the order is ready to be exported (trade event 3) until payment is made (trade event PMT), $\overline{T_{3,PMT}^{n}}$.[†] Again, this

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[*] More precisely, $\pi_1^{n-1} \leq \pi_0^n$ since the unit cost at the downstream firm may include some extra logistics costs different form the purchase price. However, for ease of notation we will assume they are equal.
[†] We are not including the cost of work-in-progress product that will be incurred during $\overline{T_{2,3}}$ since they are related to the manufacturing/fulfillment strategy of the supplier

interval may be negative when the supplier requires payment prior to start fulfilling the buyer's order. From the seller perspective, the FCA trade terms (i.e. his responsibility for the goods and costs to the point of export) are not necessarily related to the cost of capital associated to waiting for the payment.

Third, the seller cost function includes both Q^n, the EOQ of the buyer, and Q^{n-1}, the EOQ of the raw materials the seller needs from tier 2 suppliers. Although the annual expected demand $\bar{D}$ faced by the seller is the same as the buyer, it faces different trade offs between the costs of raw materials ($\pi_1^{n-2} = \pi_0^{n-1}$), holding cost of raw materials (r^{n-1}), tier 2 suppliers lead time ($T_{4,7}^{n-1}$) and its cost of ordering from tier 2 suppliers ($A^{n-1}, c_{Q^{n-1}}^{n-1}$).

Finally, if both buyer and seller have the same target service levels and if there is no lead time variability, it is expected that $\bar{I}_{SS}^{n-1} > \bar{I}_{SS}^n$ due to the amplification variability of demand due to the bullwhip effect (Lee et al. 2004). There is however, no relationship between lead time variability experienced by the buyer and lead time variability experienced by the seller. It may be argued that lead time variability of the international trade will tend to be higher than local lead time variability, due to the variety of actors involved but in development countries with poor infrastructure this may not be the case.

Now, if all upstream suppliers $m = 1, \dots, n-2$ purchase items locally or EXW and are paid upon collection of the item ($\overline{T_{3,6}^m} = \overline{T_{PMT,6}^m}$), the cost for each of them will be given by:

Eq. 6

$$TC^m = \frac{Q^m}{2} \cdot \pi_1^{m-1} \cdot r^m + \bar{d} \cdot \overline{T_{3,6}^m} \cdot \pi_1^{m-1} \cdot r^m + (A^m + F^{EXW,m}) \cdot \frac{\bar{D}}{Q^m}$$

$$+ c_{Q^m}^{EXW,m} \cdot \frac{\bar{D}}{Q^m} + \bar{I}_{SS}^m \cdot \pi_1^{m-1} \cdot r^m + \bar{I}_{SO}^m \cdot \pi_1^m \cdot \xi^m \cdot \frac{\bar{D}}{Q^m}$$

where $F^{EXW,m}$ are any additional trade ordering costs to support EXW terms (when applicable) and $c_{Q^m}^{EXW,m}$ the inbound transportation cost of an order under EXW, or local transport whenever the upstream firm is in the same country. Also, π_1^0 will represent the cost of extracting goods from earth for firm 1.

We can now write an expression for the total supply cost as follows:

$$\text{Total Supply Chain Cost (TSC)} = \sum_{m=1}^{n} TC^m =$$

Supply Chain Cost for EXW and immediate payment upon delivery

$$\sum_{m=1}^{n} \left(\frac{Q^m}{2} \cdot \pi_1^{m-1} \cdot r^m + \bar{d} \cdot \overline{T_{3,6}^m} \cdot \pi_1^{m-1} \cdot r^m + \left(A^m + F^{EXW,m} + c_{Q^m}^{EXW,m} \right) \cdot \frac{\bar{D}}{Q^m} + \bar{I}_{SS}^m \cdot \pi_1^{m-1} \cdot r^m + \bar{I}_{SO}^m \cdot \pi_1^m \cdot \xi^m \cdot \frac{\bar{D}}{Q^m} \right)$$

$$+ \left(\left(c_{Q^n}^{FCA,n-1} - c_{Q^n}^{EXW,n-1} \right) + \left(c_{Q^n}^{FCA,n} - c_{Q^n}^{EXW,n} \right) \right) \cdot \frac{\bar{D}}{Q^n} + \left(\left(F^{FCA,n-1} - F^{EXW,n-1} \right) + \left(F^{FCA,n} - F^{EXW,n} \right) \right) \cdot \frac{\bar{D}}{Q^n}$$

$\underbrace{}$ Differential buyer-seller transportation costs between EXW and FCA $\qquad$ $\underbrace{}$ Differential buyer-seller trade ordering costs between EXW and FCA

Eq. 7

$$- \underbrace{\bar{d} \cdot \left(\overline{T_{3,4}^n} + \overline{T_{4,PMT}^n} \right) \cdot \pi_1^{n-1} \cdot r^n}_{\substack{\text{Differential buyer cost of capital inventory in-transit} \\ \text{between EXW and FCA and contract terms}}} \quad + \quad \underbrace{\bar{d} \cdot \overline{T_{3,PMT}^n} \cdot \pi_1^{n-1} \cdot r^{n-1}}_{\substack{\text{Differential seller cost of capital sold goods} \\ \text{awaiting payment due to contract terms}}} \quad +$$

$$- \underbrace{\Delta_{SS}^{FCA,n} \cdot \pi_1^{n-1} \cdot r^n + \Delta_{SO}^{FCA,n} \pi_1^n \cdot \xi^n \cdot \frac{\bar{D}}{Q^n}}_{\substack{\text{Differential in buyer inventory risk due to change in lead time} \\ \text{variability between EXW and FCA}}}$$

The first term of the total supply chain cost is the cost for each firm assuming each of them trade in EXW terms or equivalently, picks up goods from the warehouse of the upstream firm. Also, each of the firms pays the upstream firm immediately after goods are collected. The second expression adds any differential transportation costs of the international seller-buyer transaction (firms n-1 and n respectively) where $c_{Q^n}^{FCA,n}$ represents the transport costs under FCA terms. The third term estimates any changes in the cost of facilitating the transaction between FCA and EXW, where $F^{FCA,n}$ represents the trade facilitation costs under FCA terms. The fourth terms captures the impact on the cost of capital for the buyer firm under FCA. Since the buyer now takes ownership of the goods at trade milestone (4), we need to reduce the in-transit inventory cost of capital during $\bar{T}_{3,4}^n$. Also, since the contract terms between buyer and seller may specify a different payment timeline due to a different point of ownership, a cost of capital adjustment is also needed during $\bar{T}_{4,PMT}^n$ as in Eq. 4. When payment terms are identical between EXW and FCA negotiations, $\bar{T}_{4,PMT}^n = \overline{T_{4,3}^n}$ and there will not be any capital adjustment for the buyer. The fifth term does the same but for the seller cost of capital while it awaits payment of goods delivered. Finally, since a portion of the in-bound transit time is no longer under control of the buyer ($\bar{T}_{3,4}^n$), this may impact the lead time variability σ_T^2, and therefore the safety stock levels $\bar{I}_{SS}^n$ and the expected out-stock units $\bar{I}_{SO}^n$ calculations. $\Delta_{SS}^{FCA,n}$ and $\Delta_{SO}^{FCA,n}$ represent these net impacts between FCA and EXW inventory levels.

3.2.3 Firm Costs Under Other Trade Scenarios
The resulting Eq. 7 can be easily modified to compare wide range of trade scenarios. It allows comparing the *marginal* supply chain cost impact of a buyer-seller international trade transaction using specific EXW terms as a baseline. For example, under DDP, besides the direct adjustment due to

transportation costs ($c_{Q^n}^{DDP,n}$), trade ordering costs ($F^{DDP,n}$) and inventory safety stock ($\Delta_{SS}^{DDP,n}$ and $\Delta_{SO}^{DDP,n}$), the following will be the adjustments for cost of capital for both buyer and seller:

$$- \underbrace{\bar{d} \cdot (\overline{T_{3,6}^n} + \overline{T_{4,PMT}^n}) \cdot \pi_1^{n-1} \cdot r^n}_{\substack{\text{Differential buyer cost of capital inventory in-transit} \\ \text{between EXW and DDP and contract terms}}} \quad + \quad \underbrace{\bar{d} \cdot \overline{T_{3,PMT}^n} \cdot \pi_1^{n-1} \cdot r^{n-1}}_{\substack{\text{Differential seller cost of capital sold goods} \\ \text{awaiting payment due to contract terms}}}$$

<div align="right">Eq. 8</div>

Notice in Eq. 8, that the only adjustment required to capture the new cost of capital adjustment structure for the buyer under DDP (compared to EXW), is the removal of any in-transit inventory holding costs ($\overline{T_{3,6}^n}$) for the buyer. The rest of the cost of capital adjustments remains the same, as they are not directly related to the Incoterm selected.

4   Numerical Example

The derived expressions can be used to analyze supply chain costs impacts under a variety of scenarios of trade facilitation. We have selected a two-echelon supply chain (2E-SC, buyer and seller) for a functional product (galvanized steel) in the metal mechanic industry, where the buyer purchases from an international exporter in the Caribbean Area (Port of Barranquilla) according to FCA rules.

4.1   Parameter estimation

We assume ocean mode for the international transportation. The cost estimated for international transportation is 80 USD/ton, and the cost estimated for local transportation (inland transportation cost) is 6 USD/ton.

Table 1 shows the parameter estimated for the buyer firm:

VAR	Buyer Firm (n) - Model Parameters	Value
ρ	Unit margin	0.05
K	K	1.645
D	Annual expected demand	30000
d	Daily expected demand	82
σdn	Standard deviation of daily demand	12
π0 (n)	Per unit cost (dollars)	972
π1(n)	Unit sale price (dollars)	1021
Qn	The economic order quantity, EOQ	200
An	Ordering cost per order (dollars)	200
Fn	Trade Facilitation Cost per international order	1000
cQn	Transportation cost per order of Q units (dollars)	16000
rn	Cost of capital for firm n (rn=h1=h2=h3)	0.04
ξn	Stock out cost per unit of items short (percentage of unit sale price)	0.5
T1,7	Order placement and buyer goods receipt	47
T5,7	International Trade lead time (from port to buyer reception)	17
T5,9	Goods ready at port of export and payment	47
σTn	Standard deviation of lead time of incoming orders (days)	16.45
Issn	Expected inventory safety stock	2228
Ison	Expected stock out per cycle	0.26

Table 1. Parameter estimation for the buyer firm

Table 2 shows the parameter estimated for the seller firm:

VAR	Seller Firm (n-1) - Model Parameters	Value
ρ	Unit margin	0.08
K	K	1.645
D	Annual expected demand	30000
d	Daily expected demand	82
σd(n-1)	Standard deviation of daily demand (units)	18
π0(n-1)	Per unit cost (dollars)	900
π1(n-1)	Unit sale price (dollars)	972
Q(n-1)	The economic order quantity, EOQ (units)	800
A(n-1)	Ordering cost per order (dollars) (for orders placed upstream to Tier 2 supplier)	100
Fn-1	Trade facilitation cost - for orders from the buyer (international orders)	850
cQ	Transportation cost per order of Q units (dollars) - to FOB	1200
CQn-1	Transportation cost per order of Q (n-1) units (dollars) - from tier 2 supplier	4800
rn-1	Cost of capital for firm (n-1)	0.06
ξ(n-1)	Stock out cost per unit of items short (percentage of unit sale price)	0.5
T4,7(n-1)	Seller Lead Time between goods ready at supplier (n-2) and seller receives the goods	0
T1,4	Lead time between order received (1) and order to dispatch (4) at seller premises	25
T1,5	Lead time between order received (1) and order at exporter port	30
T1,7	Lead time between good receipt by the buyer (7) and order placement (1)	47
T5,9	Supplier invoice-to-cash cycle (in days), between goods payment (9) and goods ready to export (5)	47
T3,9	Supplier fullfilment-to-cash cycle (in days), between goods payment (9) and start of order fulfilment (3)	52
σT(n-1)	Standard deviation of lead time of incoming orders (days)	0
Iss(n-1)	Expected inventory safety stock	0
Iso(n-1)	Expected stock out units per cycle	0.39

Table 2. Parameter estimation for the seller firm

Based on these parameters we can now compare the supply chain cost impact of different trade scenarios.

4.2 Results Analysis

The impact of three Incoterms rules: DDP, ExW and FCA are analyzed in this section.

Table 3 shows the results of this numerical example. The total supply chain trade cost model for this example shows that the total buyer firm cost under the DDP rule is bigger (almost the triple) than the total seller firm cost.

DDP						
Supply Chain Cost	**Buyer Firm**	**%**	**Seller Firm**	**%**	**Supply Chain**	**%**
Inventory carrying cost	3,888.00	0.1%	21,600.00	3.2%	25,488.00	0.8%
In-transit carrying cost	(95,868.49)	-3.7%	249,258.08	37.0%	153,389.59	4.7%
Ordering cost	30,000.00	1.2%	3,750.00	0.6%	33,750.00	1.0%
Trade Management cost	150,000.00	5.8%	31,875.00	4.7%	181,875.00	5.6%
Transportation cost	2,400,000.00	92.5%	360,000.00	53.5%	2,760,000.00	84.5%
Safety stock cost	86,643.00	3.3%	-	0.0%	86,643.00	2.7%
Stockout cost	19,686.46	0.8%	7,030.88	1.0%	26,717.34	0.8%
Total Cost	**2,594,348.97**	**100%**	**673,513.96**	**100%**	**3,267,862.93**	**100%**
Total Cost as % SC Cost	**79.4%**		**20.6%**		**100%**	
Total Cost as % revenue	**8.5%**		**2.2%**		**10.7%**	

Table 3. Supply Chain Cost Calculations for DDP terms

The total buyer firm cost represents the 79.4% of the total SC trade cost under DDP rule, while the total seller cost represents 20.6%. The total SC trade cost represents a 10.7% of the revenue of the supply chain analyzed in this numerical example.

We also applied the model under the ExW Rule. Table 4 summarizes the supply chain cost for the buyer and the seller firm under these terms.

EXW						
Supply Chain Cost	**Buyer Firm**	**%**	**Seller Firm**	**%**	**Supply Chain**	**%**
Inventory carrying cost	3,888.00	0.1%	21,600.00	3.8%	25,488.00	0.8%
In-transit carrying cost	(25,564.93)	-1.0%	143,802.74	25.3%	118,237.81	3.7%
Ordering cost	30,000.00	1.1%	3,750.00	0.7%	33,750.00	1.0%
Trade Management cost	150,000.00	5.6%	31,875.00	5.6%	181,875.00	5.6%
Transportation cost	2,400,000.00	90.1%	360,000.00	63.4%	2,760,000.00	85.4%
Safety stock cost	86,643.00	3.3%	-	0.0%	86,643.00	2.7%
Stockout cost	19,686.46	0.7%	7,030.88	1.2%	26,717.34	0.8%
Total Cost	**2,664,652.53**	**100.0%**	**568,058.62**	**100.0%**	**3,232,711.15**	**100.0%**
Total Cost as % SC Cost	**82.4%**		**17.6%**		**100%**	
Total Cost as % revenue	**8.7%**		**1.9%**		**10.6%**	

Table 4. Supply Chain Cost Calculations for ExW terms

With ExW rule, the total cost of the buyer as a percentage of the SC cost is bigger than in the DDP rule.

Table 5 summarized the results under the FCA rule.

FCA						
Supply Chain Cost	Buyer Firm	%	Seller Firm	%	Supply Chain	%
Inventory carrying cost	3,888.00	0.1%	21,600.00	3.6%	25,488.00	0.8%
In-transit carrying cost	(41,543.01)	-1.6%	167,769.86	28.3%	126,226.85	3.9%
Ordering cost	30,000.00	1.1%	3,750.00	0.6%	33,750.00	1.0%
Trade Management cost	150,000.00	5.7%	31,875.00	5.4%	181,875.00	5.6%
Transportation cost	2,400,000.00	90.6%	360,000.00	60.8%	2,760,000.00	85.2%
Safety stock cost	86,643.00	3.3%	-	0.0%	86,643.00	2.7%
Stockout cost	19,686.46	0.7%	7,030.88	1.2%	26,717.34	0.8%
Total Cost	2,648,674.45	100.0%	592,025.74	100.0%	3,240,700.19	100.0%
Total Cost as % SC Cost	81.7%		18.3%		100%	
Total Cost as % revenue	8.7%		1.9%		10.6%	

Table 5. Supply Chain Cost Calculations for FCA terms

Comparing the tree scenarios, ExW rule gives the bigger cost for the buyer, 82.43% vs. 79.39% in DDP, since DDP gives the bigger cost for the seller (20.61% vs. 17.57% in ExW). Table 6 shows these results. Note that, the lowest total supply chain cost for this example is achieved under ExW.

Incoterm Rules	DDP	ExW	FCA
Seller SC Trade Costs	20.61%	17.57%	18.27%
Buyer SC Trade Costs	79.39%	82.43%	81.73%
Total SC Trade Impact	10.67%	10.56%	10.58%

Table 6. Comparison among different scenarios in a 2E-SC

4.3 Sensitivity analysis

The parameters modified for the sensitivity analysis are shown in Table 7. A total of 21 scenarios, varying each of the parameters within the ranges were analyzed.

VAR	Parameter Settings	From	To
ρ_n	Buyer unit margin cost	5%	110%
ρ_{n-1}	Seller unit margin cost	8%	176%
r_n	Buyer cost of capital	4%	88%
r_{n-1}	Seller cost of capital	6%	132%
$T_{5,6}$	International trade time (days)	10	210
$T_{6,PMT}$	Lead time between goods receipt and payment (days)	10	210

Table 7. Parameter settings

Figure 4 depicts the numerical results of the sensitivity analysis.

a) ρ_n c) r_n e) $T_{6,PMT}$
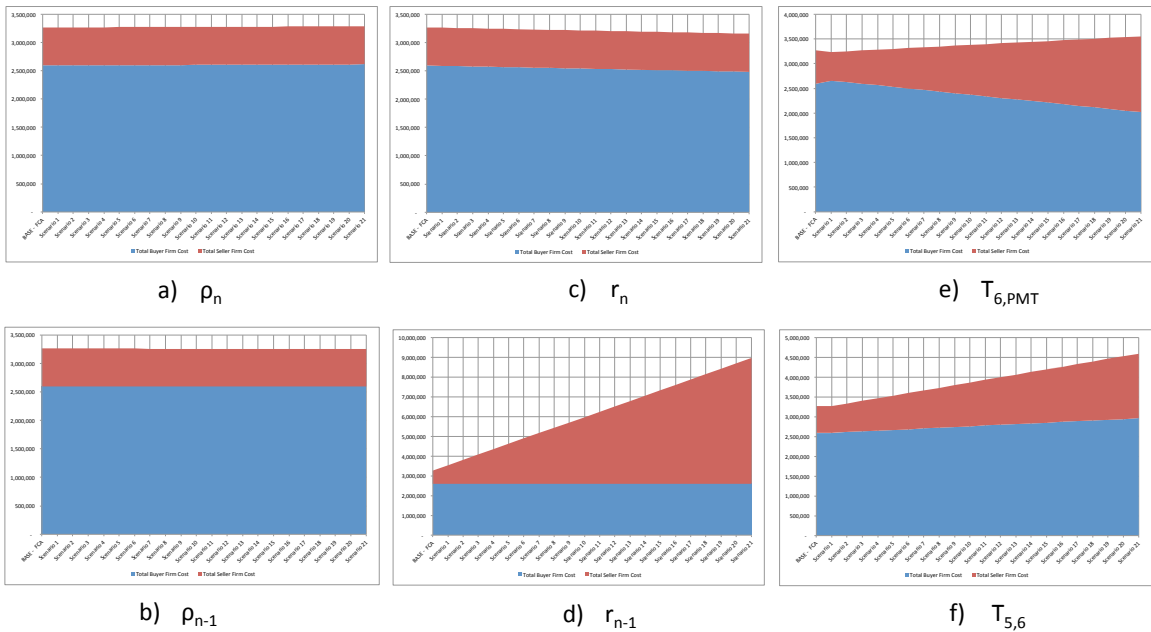
b) ρ_{n-1} d) r_{n-1} f) $T_{5,6}$

Figure 4. Total supply chain trade cost for varying parameter settings

In Figure 4, a) and b) we can observed that and increase of the unit margin cost does not affect the allocation of the buyer and seller trade firm costs.

The impact of varying the buyer unit margin cost (ρ_n), affects on the one hand, on the buyer stock out cost, increasing in $1,000 per 1 unit of increase in the buyer unit margin cost factor. On the other hand, the USD value of the demand also increases with this varying in the parameter settings, and the percentage that the total trade cost of the SC represents from the revenue decrease 0.5%, when the buyer unit margin cost changes from 5 to 10%.

Variations in the seller unit margin cost (ρ_{n-1}) do not affect at all the total trade SC cost (the total SC trade cost is very similar in all scenarios and the percentage of this total SC trade cost stay almost even). Regarding the total seller firm cost, the inventory carrying cost is the only part of the cost that decreases in approximately $1,500 per 1 unit of increase in the seller unit margin cost factor.

When the buyer cost of capital (r_n) increase, see Figure 4 c), the total SC trade cost slightly decrease. The buyer inventory carrying cost and also the safety stock cost increase, but the in-transit cost further decreases, so the total buyer firm cost slightly decreases.

However, setting variations in the seller cost of capital (r_{n-1}) depicted in Figure 4 d) have a strong effect in the results. The total buyer firm cost stay even, but the total seller cost exponentially increases with this factor. Seller inventory carrying cost and in-transit carrying cost increase. When the seller cost of capital double from 6 to 12%, the total seller firm cost increase in a 6% (from 21 to 27%). Finally, the total SC trade cost increase almost 1% as a percentage of revenue.

The effect of increasing the lead time between goods receipt at buyer facilities and seller receives payment has been also analyzed and represented in Figure 4, e). Total buyer firm cost decrease, since the buyer has more time for paying for the goods received, and total seller firm cost increase (the seller needs to finance the goods during more time). The total SC trade cost increase 0.1% per each 20 days of $T_{6,PMT}$.

The impact of delays in the international trade transportation time ($T_{5,6}$) is also significant, see Figure 4, f). If we increase 10 days this time we observe that the buyer safety stock cost increase in 1% per each 10 days of increasing, and the seller in-transit carrying cost increase also in a 4%. In consequence, the total seller firm cost increase and obviously the total SC trade cost.

5 Acknowledgements

6 References

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