Collective Profitability and Welfare in Selling-Buying Intermediation Processes

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Abstract. We consider tree-like intermediation business processes that guide the selling-buying activities through a set of transaction chains. A seller is reaching the market of potential buyers that are interested in its products through a set of intermediaries, rather than acting directly on the market. This process generates a tree-structured complex e-commerce transaction. In this paper we propose a formal model of such transactions based on rooted trees and welfare economics. This model enabled us to obtain theoretical results regarding the definition of collectively profitable intermediation transactions and optimal pricing strategies of the transaction participants.

Keywords: Welfare economics · Formal model · Linear algebra · Multi-agent system

1 Introduction

Most often a business does not make its products directly available to the potential customers. Rather, the business is using a complex business process that is responsible for the management of its distribution activities. The distribution sector is in charge with providing the methods, processes and strategies for bringing the products of the business to the market of potential customers that need those products and are interested to buy them.

Typically a manufacturing or wholesale business that is interested in selling its products will use one or more distribution channels. They represent groups of individuals or organizations that are responsible for directing the flow of products from the producers to the market of potential customers that are interested in purchasing them. A distribution channel contains a set of one or more marketing intermediaries. A marketing intermediary is an agent that links a seller to a customer or to another intermediary with the overall goal of linking the initial or root seller to its ultimate buyers. Often a seller can use multiple and different distribution channels simultaneously.

There is a long discussion about the motivation, the functions and the types of distribution channels and marketing intermediaries from an economics perspective [6]. However, in this paper the focus in on defining a simple, yet formal model of intermediation, from a computer science perspective.

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In particular, our approach is based on the agent metaphor, here understood in a computational context, as a new model of a "computer system situated in some environment that is capable of flexible autonomous action in order to meet its design objectives" [5].

Our main contribution is the definition of a formal model of intermediation as a multi-agent system (MAS hereafter) containing the producer (or seller), the intermediaries and the customers (or buyers). Here a MAS is a computational system containing a collection of loosely-coupled agents representing the participants of the intermediation process, that interact to solve the given intermediation problem. Then, using the techniques of linear algebra and welfare economics we are able to formulate collective profitability conditions and optimal pricing strategies of the participants to the intermediation transaction.

2 A Formal Model of Intermediation

Let us consider a seller agent denoted with S that is interested to bring its set of products $1, 2, \ldots, k$, $k \geq 1$ to the market of potential customers. The seller can sell the products directly to the customers or it can use a set of intermediaries. Let us denote the customers interested to buy the products with $B_1, B_2, \ldots, B_r$ such that customer B_i is interested to buy a subset $P_i \subseteq \{1, 2, \ldots, k\}$ of the products, for all $1 \leq i \leq r$. We assume that $P_i \cap P_j = \emptyset$ for all $1 \leq i \neq j \leq r$ and that $\cup_{i=1}^{r} P_i = \{1, 2, \ldots, k\}$, so sets $\{P_i\}_{i=1}^{r}$ define a partition of $\{1, 2, \ldots, k\}$.

Furthermore, let us denote with $I_1, I_2, \ldots, I_x$ the intermediaries. We assume that there are $x \geq 0$ intermediaries. An intermediary has a dual role of buyer, as well as of seller. It buys one or more products from a generic seller that can be either S or another intermediary. Then it sells a (subset of) those products to other generic buyers that can be either customers B_j or other intermediaries.

The business process that describes the complex intermediation activity that enables seller S to sell its products to buyers B_i for all $1 \leq i \leq r$ can be modeled as a tree rooted as S. In what follows we call this structure an *intermediation tree.*

Intuitively, an intermediation tree is defined as a rooted tree [3] starting with its root S. Then, we define the children of the root either as intermediaries selling subsets of the set of products or customers that buy directly from the seller S. Now, each intermediary has a role which is similar to the seller S and the process can be continued recursively for each intermediary. Note that the growth of the intermediation tree is potentially infinite as an intermediary I_i selling a subset P of products can decide to sell the whole set P to another intermediary I_j with $i \neq j$. Nevertheless, we require that the intermediation tree is finite, in order to describe a realistic intermediation transaction consisting of a finite number of selling-buying activities.

This intuition is captured by the following definition of an intermediation tree.

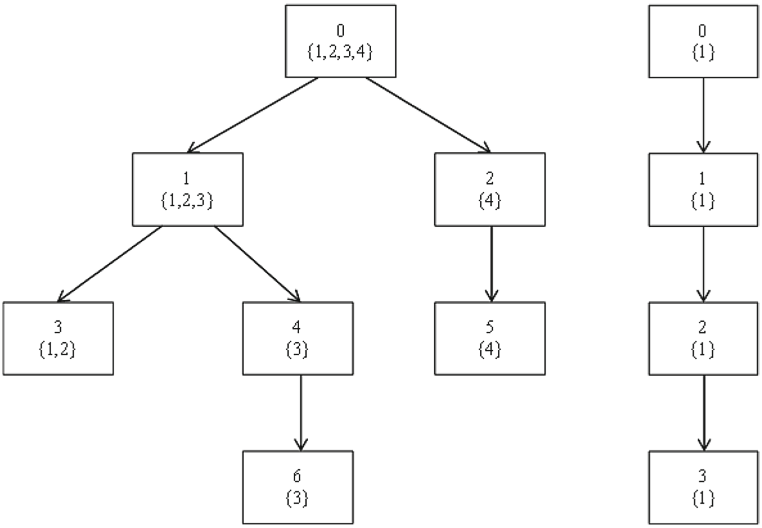
Definition 1 (Intermediation Tree). *Let us consider one seller S that is interested to sell $k \geq 1$ products to r customers $B_1, B_2, \ldots, B_r$ such that customer B_i is interested to buy a subset P_i of products for all $1 \leq i \leq r$ and sets $\{P_i\}_{i=1}^{r}$ define a partition of $\{1, 2, \ldots, k\}$. The* intermediation tree *is a rooted tree defined as follows:*

(i) *The tree contains* internal nodes *representing the seller (the root of the tree) or the other intermediaries, as well as* external nodes *or* leaves, *representing the customers. Therefore sometimes the root of the tree is represented with S (the seller), while a leaf node is represented using the label of the associated customer B_i.*

(ii) *Each tree node N has associated a nonempty subset of the set $\{1, 2, \ldots, k\}$. This set is denoted with $set(N)$.*

(iii) *The root is labeled with set $\{1, 2, \ldots, k\}$, i.e. $set(S) = \{1, 2, \ldots, k\}$.*

(iv) *Let X be an internal node and let us denote with $\mathcal{Y}$ its nonempty set of children. Then the set $\{set(Y) | Y \in \mathcal{Y}\}$ is a partition of $set(X)$.*



a.Sample intermediation tree. b.Sample intermediation chain.

Fig. 1. Intermediation trees.

If S denotes the root of an intermediation tree then $set(S)$ denotes the set of products being sold by seller S.

If N is an internal node different from S then N represents an intermediary. $set(N)$ represents the set of products bought by N from the business partner represented by the parent of N and further sold to the partners represented by the children of N.

If N is an external node (or leaf) then N represents an end customer interested in purchasing products $set(N)$.

Note that in an intermediation tree, products are transferred top down from the root to its leaves, while money are transferred bottom-up from the leaves to its root.

Figure 1a illustrates a sample intermediation tree with 7 nodes, such that the root is represented by node 0, and the leafs are denoted by 3, 6 and 5. Here the seller is selling 4 products, i.e. the set associated to the root is $set(0) = \{1, 2, 3, 4\}$. The end customers are represented by node 3 interested to buy products 1 and 2, node 6 interested to buy product 3, and node 5 interested to buy product 4.

Note that in this case there are 3 true intermediaries (excluding the root) represented by internal nodes 1, 2, and 4. For example the intermediary represented by node 1 buys products 1, 2, and 3 from the seller, and sells products 1 and 2 directly to the customer represented by node 3, and sells product 3 to the intermediary represented by node 4. Moreover, the intermediary associated to node 2 simply resells product 4 to the customer associated to leaf node 5.

Each arc of an intermediation tree from node N to a child node M defines a simple transaction where the intermediary or root seller corresponding to N sells the set of products $set(M) \subseteq set(N)$ to the intermediary or end customer corresponding to M.

Proposition 1 (Number of Transactions). *Let us assume that in an intermediation tree there are r nodes representing customers and x internal nodes representing true intermediaries. Then the tree defines a number of $t = r + x$ transactions.*

This result follows almost trivially from the fact that in a free tree with n nodes there are always $n - 1$ edges [3]. For example, referring to the intermediation tree from Fig. 1a, we have $t = 6$, $r = 3$ and $x = 3$, so the equality stated by Proposition 1 holds.

A specific type of intermediation tree is the *intermediation chain*. Here each node of the tree has at most one child, so overall, the tree has a linear shape. It obviously holds that each node of an intermediation chain has associated the same set of products. An example is shown in Fig. 1b.

A simple analysis reveals that any intermediation tree can be decomposed into a set of intermediation chains, following each path from the root to one of its leaves. So, an intermediation tree with r leaves can be decomposed into r intermediation chains. For example, the tree shown in Fig. 1a can be decomposed into 3 chains as follows: (i) $(0, \{1, 2\}) \to (1, \{1, 2\}) \to (3, \{1, 2\})$; (ii) $(0, \{3\}) \to (1, \{3\}) \to (4, \{3\}) \to (6, \{3\})$; and (iii) $(0, \{4\}) \to (2, \{4\}) \to (5, \{4\})$.

Note that this decomposition is consistent with the observation that we made in the introduction, i.e. that a seller can use multiple and different distribution channels simultaneously.

3 Profitability

An intermediation tree defines rigorously the hierarchical structure of a complex intermediation transaction. The analysis of how such structures get created is beyond the scope of this paper. Nevertheless, we can speculate that seller, intermediation and buyer agents can use the techniques provided by middle-agents and interaction protocols to incrementally define such an intermediation tree [1,2].

In this section we define and assign economic information to an intermediation tree. Then we analyse the property of profitability of an intermediation tree and we define optimal and stable pricing strategies of the participants of an intermediation tree.

Let $Q \subseteq \{1, 2, \ldots, k\}$ be a nonempty subset of products.

We denote with s_Q the limit price of seller S for selling the whole set Q of products. This means that S will agree to sell the whole set Q of products only for a price p such that $p \geq s_Q$.

Similarly, we denote with b_Q the limit price of an end customer B for agreeing to pay and buy the whole set Q of products. This means that B will agree to buy the whole set Q of products only for a price p such that $p \leq b_Q$.

We can assign economic information about limit prices to an intermediation tree as follows:

(i) The root node S is annotated with the seller limit price denoted with s. Actually s should be written as $s_{1,2,\ldots,k}$, but we omit the indices because in this case the meaning is obvious, as s means the limit price of seller S for selling the whole set $\{1, 2, \ldots, k\}$.

(ii) Each leaf node B_i representing an end customer is annotated with the limit price $b_{set(B_i)}$, for each $1 \leq i \leq r$.

For example, referring to the intermediation tree presented in Fig. 1a, the root node 0 is annotated with limit price s, node 3 is annotated with limit price b_{12}, node 6 is annotated with limit price b_3, and node 5 is annotated with limit price b_4.

In what follows we assume that an intermediation tree will also include information about limit prices.

An intermediation tree can be annotated with information about transaction prices as follows. Each arc linking node i to its child j is annotated with the price $p_j > 0$ of the transaction between seller i and buyer j for selling products $set(j)$, for all $1 \leq j \leq t$, where t is the number of tree nodes (excluding the root, with index 0) with indices $1, 2, \ldots, t$.

For example, referring to Fig. 1a, the arc linking node 1 to node 4 is annotated with transaction price p_4.

Let us first consider a potential selling-buying transaction between a generic seller S with limit price s and a generic buyer B with limit price b. Let us also assume that the agreed transaction price is p. The utility gained by seller S is $p - s$ and the utility gained by buyer B is $b - p$. This transaction is profitable if and only if both participants gain, i.e. $p-s \geq 0$ and $b-p \geq 0$. It follows trivially that the transaction is collectively profitable for B and S if and only if $b \geq s$. In this case the transaction price can be fixed to an arbitrary value $p \in [s, b]$.

Using this observation we are interested to derive a necessary and sufficient condition such that an intermediation tree can be collectively profitable for all its participants.

Definition 2 (Collective Profitability). *Let us consider an intermediation tree with* $n+1$ *nodes such that the root node is labelled with* 0 *and the other nodes are labelled with* $1, 2, \ldots, n$. *The tree is called* collectively profitable *if and only if the tree can be annotated with transaction prices such that each transaction participant is profitable, i.e. it gains by performing the transaction.*

If u_i is the utility of participant represented by node i then i is profitable if and only if $u_i \geq 0$. u_i can be computed as follows:

(i) If $i = 0$, i.e. i is the root node then $u_0 = -s + \sum_{j \in C} p_j$ where C represents the set of children of the root node.
(ii) If i is a true intermediary node, i.e. an internal node different from the root then $u_i = -p_i + \sum_{j \in C} p_j$ where C represents the set of children of node i.
(iii) If i is a leaf node representing an end customer then $u_i = -p_i + b_{set(i)}$.

Let us denote with $children(i)$ the set of children of node i of an intermediation tree. Also let us denote with $\mathcal{L}$ the set of leaves and with $\mathcal{I}$ the set of true intermediary nodes of an intermediation tree.

Let us consider the following system of $t+1$ inequations with t variables $p_1, p_2, \ldots, p_t$:

$$\begin{aligned} -s + \sum_{j \in children(0)} p_j &\geq 0 \\ -p_i + \sum_{j \in children(i)} p_j &\geq 0 \quad i \in \mathcal{I} \\ -p_i + b_{set(i)} &\geq 0 \quad i \in \mathcal{L} \end{aligned} \tag{1}$$

The following lemma states a necessary and sufficient condition for the collective profitability of an intermediation tree.

Lemma 1. *An intermediation tree is collectively profitable if and only if there exists an annotation with transaction prices that satisfies the system (1) of inequalities.*

Using Lemma 1 we can formulate the following necessary and sufficient condition that states when an intermediation tree is collectively profitable.

Proposition 2 (Necessary and Sufficient Condition for Collective Profitability). *An intermediation tree is collectively profitable if and only if:*

$$\sum_{i \in \mathcal{L}} b_{set(i)} \geq s \tag{2}$$

We are going to prove Proposition 2 for the sample tree presented in Fig. 1a. The proof for the general case is not difficult, it follows the same idea, but the details are more technical, so it is omitted here. Moreover, using an example will be easier to understand for the reader.

Firstly, inequations (1) can be rewritten as equations, for the sample tree presented in Fig. 1a, as follows:

$$\begin{aligned} -s + p_1 + p_2 = &\quad \alpha_0 \geq 0 \\ -p_1 + p_3 + p_4 = &\quad \alpha_1 \geq 0 \\ -p_2 + p_5 = &\quad \alpha_2 \geq 0 \\ -p_3 + b_{12} = &\quad \alpha_3 \geq 0 \\ -p_4 + p_6 = &\quad \alpha_4 \geq 0 \\ -p_5 + b_4 = &\quad \alpha_5 \geq 0 \\ -p_6 + b_3 = &\quad \alpha_6 \geq 0 \end{aligned} \tag{3}$$

The condition stated by inequality (2) for the sample tree presented in Fig. 1a is defined as follows:

$$b_{12} + b_3 + b_4 \geq s \tag{4}$$

Now, if the tree is collectively profitable, according to Lemma 1, Eq. (3) have a solution. Summing up all the equations we get:

$$b_{12} + b_3 + b_4 - s = \sum_{i=0}^{6} \alpha_i \geq 0 \tag{5}$$

so condition 4 follows trivially.

Conversely, we assume that condition (4) is true and we build an annotation of the tree with limit prices $p_i \geq 0$, for all $i = 1, 2, \ldots, 6$ such that inequalities (1) hold. This is reduced to finding $\alpha_i \geq 0$ such that equations (3) are true. To simplify things, we assume that $\alpha_1 = \alpha_2 = \cdots = \alpha_6 = \alpha$ and we look for a suitable value of α.

Solving the last 6 equations of system (3), starting with the last equation, we get:

$$\begin{aligned} p_6 = &\quad b_3 - \alpha \geq 0 \\ p_5 = &\quad b_4 - \alpha \geq 0 \\ p_4 = &\quad b_3 - 2\alpha \geq 0 \\ p_3 = &\quad b_{12} - \alpha \geq 0 \\ p_2 = &\quad b_4 - 2\alpha \geq 0 \\ p_1 = &\quad b_{12} + b_3 - 4\alpha \geq 0 \end{aligned} \tag{6}$$

α_0 can be computed from the first equation of (3) as follows:

$$\alpha_0 = \quad b_{12} + b_3 + b_4 - s - 6\alpha \geq 0 \tag{7}$$

Choosing $0 \leq \alpha \leq \min\{b_3/2, b_4/2, b_{12}, (b_{12}+b_3)/4, (b_{12}+b_3+b_4-s)/6\}$ (this is possible as limit prices are positive and inequality (5) holds), conditions (6) and (7) are satisfied, so the proof is concluded.

4 Welfare Pricing Strategy

In this section we apply some concepts from welfare economics with the goal of defining optimal pricing strategies of the transaction participants. However, we were able to obtain theoretical results only for special cases, that will be outlined here. For the other situations we concluded that either more theoretical investigation is required, or specific computational methods should be employed to determine the optimal pricing strategies of the participants.

Social welfare can be determined using a *collective utility function* [4]. If $\mathcal{A} = \{a, b, \dots\}$ is the set of participant agents, and if each agent $a \in \mathcal{A}$ has an individual utility function $u_a \geq 0$ then a collective utility function U is a positive function defined as follows:

$$U(x) = \quad U(u_a(x), u_b(x), \dots) \tag{8}$$

for all $x \in \mathcal{X}$, where $\mathcal{X}$ is the space of possible offers.

Several collective utility functions are proposed in the literature.

Utilitarian social welfare uses the following collective utility function:

$$U_{usw}(x) = \quad \sum_{a \in \mathcal{A}} u_a(x) \tag{9}$$

Egalitarian social welfare uses the following collective utility function:

$$U_{esw}(x) = \quad \min_{a \in \mathcal{A}} u_a(x) \tag{10}$$

Nash social welfare uses the following collective utility function:

$$U_{nsw}(x) = \quad \prod_{a \in \mathcal{A}} u_a(x) \tag{11}$$

In what follows we apply these collective utility functions to determine the optimal pricing strategy for the participants of an intermediation process. The results basically follow from the following lemma.

Lemma 2. *Let $\mathcal{A}$ be a set of agents and let $\mathcal{X}$ be their space of offers. Let us assume that the utilitarian social welfare function $U_{usw}(x)$ is constant for all offers $x \in \mathcal{X}$ and that there exists an offer $x^* \in \mathcal{X}$ and a constant K such that $u_a(x^*) = K$ for all $a \in \mathcal{A}$. Then the maximum of all the collective utility functions is obtained for $x = x^*$.*

The result stated by Lemma 2 follows from few simple arguments.

Let $U = U_{usw}(x)$. Trivially it follows that $K = U/|\mathcal{A}|$. Using the inequality of arithmetic and geometric means, we have $U_{nsw}(x) \leq (U/|\mathcal{A}|)^{|\mathcal{A}|}$. We get equality if the individual utilities of all the agents are equal, i.e. when $x = x^*$, so $U_{nsw}(x)$ is maximum when $x = x^*$.

Let x be an offer for which at least two agents have distinct utilities. It follows that the agent for which the utility is minimum has a utility that is strictly less then the arithmetic mean $U/|\mathcal{A}| = K$. So $U_{esw}(x) < K$. Then the maximum of $U_{esw}(x)$ is K and it is obtained when $x = x^*$.

Let us now consider an intermediation tree with $t+1$ nodes numbered from 0 (the root node) up to node t. The set of leaf nodes is denoted with $\mathcal{L}$. Let us also assume that the condition stated by inequality (2) holds, so the intermediation tree is collectively profitable. Summing up the utilities of all the participants we obtain:

$$\sum_{i=0}^{t} u_i = \sum_{i \in \mathcal{L}} b_{set(i)} - s \tag{12}$$

According to Eq. (12), the utilitarian social welfare of the participants to the intermediation transaction is constant. So we are under the assumptions of Lemma 2. It follows that the maximum of all the collective utility functions is obtained when $u_i = (\sum_{i \in \mathcal{L}} b_{set(i)} - s)/(t+1)$ for all $0 \leq i \leq t$.

Let

$$h = (\sum_{i \in \mathcal{L}} b_{set(i)} - s)/(t+1) \tag{13}$$

We can solve system (14) of equations to find transaction prices $p_1, p_2, \ldots, p_t$. They define the optimal pricing strategy of the participants to maximize their social welfare.

$$\begin{aligned} -s + \sum_{j \in children(0)} p_j &= h \\ -p_i + \sum_{j \in children(i)} p_j &= h \quad i \in \mathcal{I} \\ -p_i + b_{set(i)} &= h \quad i \in \mathcal{L} \end{aligned} \tag{14}$$

Note that system (14) has always a unique solution. Let us number tree nodes according to the breadth-first traversal [3] (see for example the tree nodes from Fig. 1a). Firstly observe that the first equation is redundant, as it follows by summing up the other t equations, so it can be omitted. Now it follows that (14) is a linear system of t equations. Moreover, the system matrix is upper triangular (i.e. the lower triangle consists only of 0s), while the elements of the diagonal are equal to -1. So the matrix is non-singular with the determinant equal to $(-1)^t$. This proves that (14) has a unique solution.

Proposition 3 (Sufficient Conditions for Maximum Social Welfare). *Let us consider an intermediation transaction such that limit prices satisfy condition (2). If system (14) has a positive solution $p_i \geq 0$ for all $1 \leq i \leq t$ then the maximum equalitarian social welfare is h and the maximum Nash social welfare is h^{t+1}. The optimal pricing strategies are defined by the solution of system (14).*

In what follows we check the application of Proposition 3 to the tree from Fig. 1a. We simplify things by assuming that $b_3 = b_4 = b$ and $b_{12} = 2b$. We obtain system (15) (the first equation of (14) was omitted, as it is redundant).

$$\begin{aligned} -p_1 + p_3 + p_4 = & \quad h \\ -p_2 + p_5 = & \quad h \\ -p_3 + 2b = & \quad h \\ -p_4 + p_6 = & \quad h \\ -p_5 + b = & \quad h \\ -p_6 + b = & \quad h \end{aligned} \tag{15}$$

Solving system (15) we obtain:

$$\begin{aligned} p_6 = & \quad b - h \\ p_5 = & \quad b - h \\ p_4 = & \quad b - 2h \\ p_3 = & \quad 2b - h \\ p_2 = & \quad b - 2h \\ p_1 = & \quad 3b - 4h \end{aligned} \tag{16}$$

Moreover:

$$h = \quad (4b - s)/7 \tag{17}$$

The transaction is collectively profitable, so $h \geq 0$, i.e. $b \geq s/4$. Now, in order to satisfy the assumptions of Proposition 3, using the equation defining p_4 (or p_2) from (16), we obtain:

$$h \leq b/2 \tag{18}$$

Combining (17) and (18) we obtain the following condition:

$$b \leq 2s \tag{19}$$

The conclusion is that if inequality (19) holds then the optimal pricing strategy can be determined using equations (16). Otherwise, if $b > 2s$ we cannot apply Proposition 3. In this case other methods, either theoretical developments or computational approaches must be used, in order to determine the optimal pricing strategy of the participants. These further developments are left as future works.

5 Conclusion

In this paper we proposed a formal model of intermediation business processes that a company can use to distribute its products to the end customers that are interested in purchasing them. The model captures a hierarchically structured intermediation transaction as a rooted tree and it can serve a company with multiple distribution channels working simultaneously. We formulated necessary and sufficient conditions for the collective profitability of such an intermediation transaction. Then we applied the concepts of welfare economics to analyze optimal pricing strategies of the transaction participants. We obtained a theoretical result stating sufficient conditions when the optimal pricing strategy of the participants can be determined by solving a simple system of linear algebraic equations. As future work we plan to strengthen this result, either by formulating tighter optimality conditions or by proposing computational methods to determine optimal pricing strategies in a more general setting. As future work we are also interested to study the stability of pricing strategies of the transaction participants using the concepts of game theory.

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