Modelling Transaction Costs in Purchasing via Probabilistic and Fuzzy Reasoning

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Abstract
Transaction costs analysis was first addressed by Coase in 1937 and is concerned with ways of aligning appropriate governance modes with the attributes of economic transactions. Nowadays transaction costs are universally accepted, but researchers in the field agree on the difficulty in measuring and quantifying them. Starting from the universally accepted definition of transaction costs, this paper proposes a model for the buyer/seller relationship, focusing on the uncertainty characterizing the exchange and the connected costs. In particular, according to a well-known classification, transaction costs are divided into \emph{ex ante} (drafting and negotiating agreements) and \emph{ex post} (monitoring and enforcing agreements) costs. More precisely, the problem of quantifying all such costs connected to the supply of a new product/service is addressed by using appropriate deterministic models for \emph{ex ante} costs and suitable statistical distributions for \emph{ex post} costs. Obviously, both such costs categories require the quantification of several parameters related to the buyer operating the transaction and to the uncertainty characterizing the buyer/seller relationship. Hence, in order to correctly evaluate the buyer behaviour, a fuzzy logic inference system is designed for synthesising, starting from expert judgments, the required data to the transaction costs model. The reported simulation experiments show the effectiveness of the proposed model in estimating the transaction costs and total costs associated with a generic transaction.

1. Introduction
The theory of Transaction Costs Analysis (TCA) builds upon the issue of the boundary of the firm, that was first addressed by Coase (1937). According to Williamson (1975, 1981), a transaction occurs when a good or service is transferred across a technology separable interface. Transactions involve costs related to the issues of finding a counterpart, drawing up a contract or monitoring the task completion. These costs are both incurred by government organizations or autonomized parts of these organizations (North, 1990).

A well-known qualitative classification of transaction costs divides them into \emph{ex ante} and \emph{ex post} costs (Buvik, 2002). In particular, \emph{ex ante} costs represent direct opportunity costs (Malone, 1987, Masten, Meehan and Snyder, 1991), which imply productivity losses resulting from the lack of appropriate employment of specific assets (Rindfleish and Heide, 1997). Moreover, \emph{ex post} transaction costs are associated with the problems of performance control, performance verification, adjustment and bargaining (Buvik and Halskau, 2001). More precisely, in a buyer/supplier relationship \emph{ex ante} costs may be viewed as the costs of research of suppliers, the negotiation costs and the costs of approving and drafting the contract. In the same case, \emph{ex post} costs consider the quality control costs and the
enforcement costs. As remarked by Shelanski and Klein (1995), transaction cost economics studies also how trading partners protect themselves from the hazard associated with exchange relationships. However, despite the numerous contributions in the related literature, research on TCA has mainly focused on descriptive and empirical predictions. Indeed, although nowadays transaction costs are universally accepted, researchers in the field agree on the difficulty in measuring and quantifying them. Motivated by such a research gap, in this paper we propose an approach to estimate (in a probabilistic way) transaction costs before the exchange is actually carried out, so that a decision support system for the buyer is available.

As far as human behaviour is concerned, TCA stresses bounded rationality: in other words, it focuses on the human behaviour characteristics to be intendedly rational, but only limitedly so, and on opportunism, i.e. self-interest seeking with guile (Simon, 1961). Hence, a certain degree of uncertainty, bounded rationality and opportunism seems to be common in practice (Bogt, 2003). However, it is difficult to quantify uncertainty, bounded rationality and opportunism. Moreover, the main characteristics differentiating a transaction from another is asset specificity, that seems to determine the governance structure of an economic organization (Williamson, 1985, 1996). In order to deal with the uncertainty typical of an exchange, the paper extends a previously proposed model for the buyer/seller transaction (Costantino et al., 2005), focusing on the uncertainty characterizing such a relationship and the connected costs. In particular, the presented model employs two different and complementary approaches: 1) statistical models and probabilistic ways of thinking, that allow the determination of the costs related to the transaction; 2) fuzzy logic based reasoning, that addresses the problem of quantifying the subjective parameters characterizing the behaviour of the buyer, that are related to the peculiar buyer/seller relationship and to the specific type of product/service. More precisely, the problem of quantifying all the transaction costs connected to the supply of a new product/service is addressed by using appropriate deterministic models for \textit{ex ante} costs and suitable statistical distributions for \textit{ex post} costs. Subsequently, in order to correctly model the behaviour of the buyer, a fuzzy logic inference system is designed. Thanks to the ability of fuzzy reasoning to incorporate qualitative knowledge with quantitative information such as real data, the necessary parameters to determine the transaction costs are estimated by way of expert judgments and qualitative rules. Based on the data obtained by the fuzzy logic inference system, the supply of a new product/service may be simulated considering all the connected transaction costs, that are determined by using appropriate statistical distributions according to the model proposed by some of the authors in Costantino et al., 2005. As a result, the buyer may quantify before actually carrying out a transaction the total costs of the supply.

We evaluate the proposed model by simulating several transactions on the basis of data obtained by interviews with a buyer of an industrial company. The simulation experiments considered in the paper
focus on three main factors of TCA: the types of the exchanged product, characterized by the product standardization level, the supply value and the trust component in the buyer/seller relationship, modelled by the supplier reliability. Several simulation experiments are reported with relation to these transaction key points. The obtained results confirm the typical behaviours of partners involved in an exchange and give buyers some useful piece of advice about how to carry on a transaction.

The paper is organised as follows. Section 2 reports the basic steps of the theoretical model of the purchasing process and Section 3 outlines the fuzzy logic inference system determining the data required by the model of the previous Section. Subsequently, Section 4 presents the simulation data and the simulation results. A Conclusion Section and a Reference Section complete the paper.

Figure 1: The seven steps of a purchasing process (Costantino and Pietroforte, 2004).

2. The Theoretical Model of the Purchasing Process

2.1. The Purchasing Process

The steps of a generic purchasing process are depicted in Figure 1. Starting from the design of the product or the choice of the service, the buyer checks the potential suppliers and contacts them. Next, the suppliers make a feasibility study in order to decide whether starting the production of the required good/service is advantageous. Hence, at the end of this process some of them refuse the job. Subsequently, the buyer starts negotiating with those suppliers who have accepted the exchange, and at last only one supplier is chosen. Finally, in order for the chosen supplier to be remunerated, his supply has to pass the quality check, otherwise a legal enforcement is possible.

The previously described purchasing process is significantly influenced by three main factors of TCA: the types of the exchanged product, the supply value and the trust component in the buyer/seller relationship. The first element influences significantly the purchasing process (Costantino and Pietroforte, 2005). The
purchasing process of a highly standardized product (e.g. basic materials or standard components) is usually characterized by:

a) a small amount of information flows with high codification levels;
b) a reduced risk of contractual hazards (because of the small amount of exchanged information and its highly codified nature) and, therefore, of opportunistic behaviour.

On the contrary, the purchasing process of a product with low standardization level is characterized by:

a) a large amount of information flows with varying extents of customization;
b) a higher risk of contractual hazards and opportunistic behaviour (because of its low level of standardization).

This situation leads to the persistence of using proven and known suppliers, independently from the possible advantages of shared idiolects.

Hence, the two types of products lead to significantly different purchasing processes.

Moreover, products with different supply values clearly lead to different levels of attention in the buying process, and then different transaction costs. More precisely, a low supply value leads to lower values of the connected transaction costs, whereas a high supply value involves higher costs of such a kind.

The third element differentiating the purchasing process is strictly connected to the buyer/seller relationship, that is characterized by different types of trust. Sako (1992) focuses on three types of trust: 1) **contractual trust**, i.e. trust in that the other party will execute the contract; 2) **competence trust**, i.e. trust in that the other party is competent; 3) **goodwill trust**, i.e. trust in that the other party is committed to the relationship and will do, whenever possible, more than what is specified in the contract. Both contractual and competence trust are necessary to carry out any buyer/seller relationship. What really distinguishes a co-operative relationship from a competitive one is that the former depends on and is sustained by the existence of goodwill trust, which is not present in the latter form of relationship.

### 2.2. The Probabilistic Model of Purchasing Price and Transaction Costs

The probabilistic model evaluating the total costs of a transaction is based on an approach previously proposed by some of the authors in Costantino *et al.*, 2005. In the following we briefly describe the statistical distributions used in the revisited model to quantify the expected costs for the supply, starting from the purchasing price. In particular, it is assumed that the probability distribution of the purchasing price is Gaussian and may thus be characterized by an average value (which is the price expected by the buyer) and a standard deviation (because the offered price varies from a supplier to another): obviously, such parameters are significantly different for a standardized or customized product. The choice of a Gauss distribution is motivated by the fact that the technologies used by different suppliers and the dimension of each of these can affect, even significantly, the charged purchasing prices. Obviously, the
standard deviation for a standardized product is lower than the one associated with a customized good: indeed, the possibility to obtain different prices for the former type of product is lower than for the latter. Figure 2 shows two examples of the probability distribution of the purchasing price for two products, corresponding to the expression:

\[ P(P_p) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(P_p-\mu)^2}{2\sigma^2}}, \]

where \( \mu \) and \( \sigma \) are the average value and the standard deviation of the considered distribution, respectively, \( P_p \) represents the purchasing price in Euros and \( P(P_p) \) is its probability value. Note that in Figure 2 the values \( \mu_1=\mu_2=25,000 \) Euros, \( \sigma_1=500 \) Euros and \( \sigma_2=2,500 \) Euros are chosen, where the pedices 1 and 2 obviously refer to the two different products. Hence, in the considered cases the first product is labelled commodity product, while the second good is indicated as an asset specific product (compare the values of \( \sigma_1 \) and \( \sigma_2 \) and the distributions depicted in Figure 2).

According to the theory first proposed by Coase (1937) and subsequently extended by Buvik (2002), the model proposed in Costantino et al., 2005 classifies the transaction costs into ex ante and ex post costs. In particular, ex ante costs are composed by:

1) the costs of research of suppliers \( C_{R} \);
2) the negotiation costs \( C_{N} \) with the suppliers that are able to supply the product;
3) the costs of drafting and approval of the contract \( C_{DA} \) with the supplier that has proposed the best
price, considering also the buyer’s preference rate, defined in the sequel, that varies from a supplier to another.

In addition, *ex post* costs are divided into:

1) the quality control costs $C_Q$.
2) the enforcement costs $C_E$.

*Ex ante* costs are expressed taking into account the time of the buyer and his hour cost and are deterministic in nature (since the times of research, contact, negotiation, drafting and approval of the contract depend only on the kind of product and the relationship with the supplier). Furthermore, quality control costs are considered as a function of the time of the quality department employee and his hour cost. In addition, enforcement costs are expressed as proportional to the time of the lawyer and his hour cost. Hence, *ex post* costs exhibit probabilistic distributions for control and enforcement times (due to the significant variations of quality control and enforcement time from a supply to another).

Accordingly, research and contact costs are expressed as follows:

$$ C_R = \sum_{i=1}^{s} c_A (t_{R_i} + t_{C_i}), $$  \hspace{1cm} (2)

where $s$ is the number of consulted suppliers, $c_A$ represents the hour cost of the buyer, and $t_{R_i}$ and $t_{C_i}$ represent respectively the research time and the contact time for the generic $i$-th supplier.

Moreover, negotiation costs may be expressed as follows:

$$ C_N = \sum_{i=1}^{a} c_A t_{N_i}, $$ \hspace{1cm} (3)

where $a$ is the number of suppliers that are able to supply the new product/service and $t_{N_i}$ is the negotiation time for the generic $i$-th supplier.

In addition, the costs of drafting and approval of the contract with the chosen supplier are:

$$ C_{DA} = c_A t_{DA}, $$ \hspace{1cm} (4)

with $t_{DA}$ representing the time of approval and drafting of the contract.

As regards the quality control costs, if $c_Q$ is the hour cost of the quality department employee and $t_Q$ represents the control time for the supply, then such costs may be determined as follows:

$$ C_Q = c_Q t_Q. $$ \hspace{1cm} (5)

Analogously, the enforcement costs are:

$$ C_E = c_E t_E, $$ \hspace{1cm} (6)

where $c_E$ indicates the hour cost of the lawyer and $t_E$ is the enforcement time.

In particular, we assume that the quality control time is modelled by a Beta distribution, while an exponential distribution is preferred for the enforcement time. Indeed, the Beta distribution fits very well
quality control costs because it presents a zero probability of a zero control time, a high probability of a low control time and a decreasing probability of a high control time. In addition, the exponential distribution is extremely suitable to model enforcement costs, since, starting from zero, the enforcement time increases as the probability density decreases. The two described distributions are characterized as follows. The Beta distribution is expressed as:

\[ P(T_Q) = \frac{1}{B(b_1, b_2)} T_Q^{b_1-1}(1-T_Q)^{b_2-1} \quad \text{where} \quad B(b_1, b_2) = \int_0^1 x^{b_1-1}(1-x)^{b_2-1} \, dx , \]  
(7)

where \( T_Q = t_Q/t_{Q_{\text{max}}} \) is the normalized control time, \( P(T_Q) \) is its probability value, \( t_{Q_{\text{max}}} \) is the quality control time maximum value for the selected supplier and \( b_1 \) and \( b_2 \) are the distribution characteristic parameters.

In addition, the exponential distribution is expressed by:

\[ P(t_E) = \frac{1}{\mu_E} e^{-\frac{t_E}{\mu_E}} \]  
(8)

where \( P(t_E) \) is the enforcement time probability value and \( \mu_E \) is the average value for the enforcement time.

The two distributions expressed by equations (7) and (8) are depicted in Figures 3a and 3b, respectively. Note that in the depicted cases the values \( b_1=2, b_2=8 \) and \( \mu_E=3h \) are chosen.

Finally, the transaction costs \( C_T \) are the summation of the previously mentioned costs, i.e. it holds:

\[ C_T = C_R + C_N + C_{DA} + C_Q + C_E . \]  
(9)

![Figure 3: The Beta probability distribution (a) and the exponential one (b) of the model.](image)

2.3. The Theoretical Model of the Transaction
The theoretical model of the transaction is composed of several steps, that are summarised in the flow chart depicted in Figure 4. In particular, according to the previously introduced estimates of the purchasing price and transaction costs, the flow chart in Figure 4 shows all the considered hierarchical levels in order to calculate the total costs of a supply. More precisely, the model starts with the buyer choosing the number \( s \) of suppliers to be consulted, so that it is possible to determine the research and contact costs \( C_R \) according to (2). Subsequently, the five steps that are briefly outlined in the sequel are executed.

![Flow Chart](image)

**Figure 4: The flow chart of the proposed theoretical model.**

**Step 1.** Identify the suppliers involved in the exchange and determine the negotiation costs. This step evaluates the number \( a \leq s \) of suppliers, among the \( s \) consulted ones, that are able to supply the required product/service. Such a number is determined by simulating the feasibility study made by the \( i \)-th supplier for \( i=1,\ldots,s \) via a uniform probability \( p_i \) of success assigned by the expert to each seller and indicating the probability that the supplier will accept to take part in the exchange. Obviously, the success probability is strictly connected both to the buyer/seller relationship and to the reliability of the considered supplier, as well as to contingent phenomena, such as strikes, supplier workloads etc. Hence, the success probability belongs to the experience of the buyer or the logistics employee.

Having identified the suppliers available for the transaction, it is now possible to determine the
negotiation costs $C_N$ according to (3).

**Step 2. Determine the purchasing price.** In this step, the Gauss distribution described by equation (1) is employed in order to determine the probability distribution of all the offers of the different suppliers. In particular, the model chooses at random $a$ purchasing prices from the distribution just mentioned. Next, the prices are compared considering the preference rate $\gamma$, defined as the percentage of the purchasing price that the buyer is willing to pay more in order to obtain the supply from a certain supplier. This rate may change from a supplier to another: for instance, for some supplier it may hold $\gamma=0$, which models the circumstance that the buyer has no preference for such a provider (e.g. the latter has never participated to a transaction with the purchaser). Finally, the chosen supplier is determined as the one exhibiting the Lowest Purchasing Price ($LPP$), defined as follows:

$$LPP = \min_{i=1,...,a} [P_{Pi} (1-\gamma_i)],$$

(10)

where $P_{Pi}$ is the generic purchasing price which is associated to the preference rate $\gamma_i$ for the $i$-th supplier.

**Step 3. Determine the costs of drafting and approval of the contract.** Once the negotiating is finished and only one supplier is chosen, it is necessary to determine the probability to draft and approve the contract. Hence, we introduce a uniform probability $P_S$ of success in drafting and approving the contract, a parameter that may depend on the reliability of the supplier. In case the agreement is not reached, a new number $a$ of suppliers among the consulted $s$ is determined: obviously, in such a case the product costs increase, because the costs already paid for the failed contract (i.e. the research and the negotiation costs) have to be added to the new ones in order to determine the total price of the requested product/service. Finally, the costs of drafting and approval of the contract $C_{DA}$ are calculated according to (4).

**Step 4. Determine the quality control costs.** This step implements the probability distribution of the control time, i.e., the Beta distribution defined by (7). Then a control time is chosen at random, so that it is possible to determine the quality control costs $C_Q$ according to (5).

**Step 5. Determine the enforcement costs.** This last step determines, in an analogous way to the previous one, the enforcement costs, that complete the transaction costs. In particular, the probability distribution of the enforcement time, i.e., the exponential distribution expressed by (8), is considered. Then an enforcement time is chosen at random to determine the enforcement costs $C_E$ according to (6).

Once all the ex ante and ex post costs are known, it is possible to determine the transaction costs by
adding them according to (9). Finally, such transaction costs are added to the purchasing price obtained in Step 2 and corresponding to the chosen supplier, in order to determine the total costs associated with the transaction.

The described theoretical model of the transaction requires as inputs several data, related to the particular buyer/seller relationship, that are synthetically represented by blocks FIS1 to FIS6 in Figure 4. The next Section shows how fuzzy logic based reasoning may be employed in order to determine these inputs to the transaction model.

3. The Fuzzy Logic Inference System

The theoretical model for the purchasing price and the transaction costs described in the previous Section is based on the evaluation of *ex ante* and *ex post* costs. Both such costs categories require the quantification of several data related to the buyer operating the transaction. In particular, some parameters characterizing the exchange are deterministic and known by the buyer or may be estimated on the basis of expert advice. These are listed in the sequel:

- the number of suppliers to be consulted $s$;
- the average purchasing price $\mu$;
- the maximum acceptable standard deviation of the purchasing price $\sigma_{\text{max}}$;
- the maximum preference rate $\gamma_{\text{max}}$;
- the standardization level of the required product $SL$, expressed as the 0÷1 degree of customization. In particular, 0 corresponds to a totally customized product, 1 to a completely standardized good and all the other values correspond to products in between;
- the supply value $SV$, expressed as the 0÷1 economic importance of the supply for the specific firm. Obviously, a value close to 0 is typical of a low supply value, while a value close to 1 is typical of a high supply value;
- the supplier reliability $R$, expressed as the 0÷1 degree of reliability. In particular, 0 corresponds to a totally unreliable supplier, e.g. a new one, 1 to a completely reliable contractor, e.g. a well-known one, and all the other values correspond to providers with characteristics in between$^1$;
- the success probability that a consulted supplier is available to bid for the product $p$;
- the probability of agreement with a supplier $P_s$;
- the hour costs $c_A$, $c_E$ and $c_C$;
- the characteristic parameter $b_1$ of the control time binomial distribution, that determines the particular shape of the distribution and hence its appropriateness in modelling the control time

$^1$ Such a concept of reliability is a synthesis of the three *trusts* quoted by Sako (1992).
phenomenon;

- all the maximum acceptable values of the time parameters connected to the transaction, i.e. the maximum research and contact times \( t_{R_{\text{max}}} \) and \( t_{C_{\text{max}}} \), the maximum negotiation time \( t_{N_{\text{max}}} \), the maximum time for drafting and approving the contract \( t_{DA_{\text{max}}} \), the maximum quality control times \( t_{Q_{\text{max}0}} \) and \( t_{Q_{\text{max}1}} \) for the limit cases \( SV=0 \) and \( SV=1 \) and finally the maximum enforcement time \( t_{E_{\text{max}}} \).

On the contrary, several other parameters descriptive of the exchange are significantly influenced from the uncertainty characterizing the transaction and are therefore subjective with respect to the buyer/seller specific relationship. These are the following:

- the standard deviation of the purchasing price \( \sigma \);
- the degree of preference of a supplier \( \gamma \);
- all the time parameters connected to the transaction, i.e. the research and contact times \( t_{R} \) and \( t_{C} \), the negotiation time \( t_{N} \), the time for drafting and approving the contract \( t_{DA} \), the quality control time \( t_{Q} \) and finally the enforcement time \( t_{E} \).

Hence, in order to correctly simulate the behaviour of the buyer, some interviews with logistic and purchasing managers, belonging to different fields, were required. Starting from such expert judgments, in this section we propose to employ fuzzy logic in order to synthesise the subjective data required for the transaction model. Indeed, fuzzy logic provides a natural framework to incorporate qualitative knowledge with quantitative information such as real data. Therefore, fuzzy reasoning is particularly suitable for determining, on the basis of the subjective and qualitative knowledge provided by the interviewed experts, the subjective transaction costs parameters required as an input to the simulation model described in the previous section. To this aim, a Fuzzy logic Inference System (FIS) is designed, composed of six different fuzzy systems, indicated in the sequel by FIS1 to FIS6.

Component FIS1 addresses the problem of determining the standard deviation of the purchasing price, normalised in the \( 0 \div 1 \) range, \( \Sigma \) on the basis of the standardization level of the required product \( SL \) by using quantitative rules. In particular, FIS1 employs two simple qualitative rules, depicted in Table 1, that evaluate the normalised standard deviation \( \Sigma \) in the \( 0 \div 1 \) range by way of the input variable \( SL \). For the sake of simplicity, the membership functions for variables \( SL \) and \( \Sigma \) of FIS1 are triangular and cross vertically at a 0.5 degree of membership (completeness level). In particular, the membership functions of the fuzzy sets Low (L) and High (H) describing the corresponding input and output variables are represented in Figures 5 and 6a, respectively. Hence, the resulting value of the standard deviation of the purchasing price

\[
\sigma = \Sigma \cdot \sigma_{\text{max}}
\]
is employed in Step 2 of the theoretical model once the standardization level of the product/service is defined and parameter $SL$ is determined.

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**FIS1**

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<td>L</td>
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*Table 1: The rule table for FIS1.*

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**FIS2**

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*Table 2: The rule table for FIS2.*

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**FIS3**

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*Table 3: The rule table for FIS3.*

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**FIS4**

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*Table 4: The rule table for FIS4.*

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**FIS5**

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*Table 5: The rule table for FIS5.*

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**FIS6**

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*Table 6: The rule table for FIS6.*
Similarly to FIS1, FIS2 addresses the problem of determining the degree of preference of a supplier, normalised in the 0÷1 range, $\Gamma$ on the basis of the supplier reliability $R$. The corresponding rule table is depicted in Table 2, where the input variable is $R$ and the output variable is the normalized degree of preference $\Gamma$ in the 0÷1 range. The corresponding triangular membership functions (with 0.5 completeness level) of the fuzzy sets describing such variables are represented in Figures 5 and 6b, respectively. The obtained output $\Gamma$ of FIS2 is employed to provide the degree of preference of each supplier to equation (10) in Step 2 of the theoretical model (see Figure 4) as follows:

$$\gamma = \Gamma \cdot \gamma_{\text{max}},$$  \hspace{1cm} (12)

where we neglected for the sake of simplicity the index indicating the generic supplier.

Moreover, FIS3 evaluates the time parameters, normalised in the 0÷1 range, connected to the research and negotiation costs, i.e. the normalised research and contact times $T_R$ and $T_C$ and the normalised negotiation time $T_N$ on the basis of the standardization level of the required product $SL$, the supplier reliability $R$ and the supply value $SV$. The rule table is depicted in Table 3 and the triangular membership functions (with 0.5 completeness level) of the fuzzy sets for the input and output variables are respectively represented in Figures 5 and 7a. Note that the fuzzy sets describing the output variables are three in number, namely Low (L), Medium (M) and High (H). The obtained outputs of FIS3 allow the evaluation of the time parameters

$$t_R = T_R \cdot t_{R_{\text{max}}},$$  \hspace{1cm} (13)

$$t_C = T_C \cdot t_{C_{\text{max}}},$$  \hspace{1cm} (14)

$$t_N = T_N \cdot t_{N_{\text{max}}},$$  \hspace{1cm} (15)

that are employed in Step 1 of the transaction theoretical model for the calculation of the research, contact and negotiation time for each supplier involved in the transaction (see Figure 4).
In addition, component FIS4 evaluates the drafting and approval of the contract time parameter, normalised in the 0÷1 range, \( T_{DA} \). This is determined on the basis of the standardization level of the required product \( SL \), the supplier reliability \( R \) and the supply value \( SV \). The rule table is depicted in Table 4 and the triangular membership functions (with 0.5 completeness level) of the fuzzy sets for the corresponding input and output variables are respectively represented in Figures 5 and 7b. Obviously, the
obtained output of FIS4 is employed in Step 3 of the transaction model for the calculation of the drafting and approval of the contract time for the selected supplier (see Figure 4) as follows:

\[ t_{DA} = T_{DA} \cdot t_{DA_{\text{max}}} \, . \]  

(16)

Furthermore, FIS5 evaluates the average quality control time, normalised in the 0÷1 range, \( M_Q \) based on the standardization level \( SL \) and the reliability of the chosen supplier \( R \). The rule table is depicted in Table 5 and the triangular membership functions (with 0.5 completeness level) of the fuzzy sets for the corresponding input and output variables are respectively represented in Figures 5 and 8a. Moreover, the maximum control time \( t_{Q_{\text{max}}} \), that depends on the supply value \( SV \), is calculated through a linear interpolation between the maximum control time values obtained by the expert in the limit cases \( SV = 0 \) and \( SV = 1 \), respectively indicated as \( t_{Q_{\text{max}0}} \) and \( t_{Q_{\text{max}1}} \), as follows:

\[ t_{Q_{\text{max}}} = \left( t_{Q_{\text{max}1}} - t_{Q_{\text{max}0}} \right) \cdot SV + t_{Q_{\text{max}0}} \, . \]  

(17)

The obtained output \( M_Q \) of the fuzzy inference system is employed in Step 4 of the transaction model in order to build the Beta distribution according to (7) as follows (Kelton et al., 1998):

\[ b_2 = b_1 \frac{M_Q}{1 - M_Q} \, , \]  

(18)

so that the normalized control time \( T_Q \) may be determined by (7) and finally by the value of \( t_{Q_{\text{max}}} \) calculated according to (17) the control time is calculated as follows:

\[ t_Q = T_Q \cdot t_{Q_{\text{max}}} \, . \]  

(19)

The last component of the fuzzy logic system is FIS6, that evaluates the average enforcement time, normalised in the 0÷1 range, \( M_E \) based on the three inputs \( SL \), \( R \) and \( SV \). The rule table is depicted in Table 6 and the triangular membership functions (with 0.5 completeness level) of the fuzzy sets for the corresponding input and output variables are respectively represented in Figures 5 and 8b. The obtained result is employed in order to determine the average enforcement time as follows:

\[ \mu_E = M_E \cdot t_{E_{\text{max}}} \, , \]  

(18)

so that in Step 5 of the transaction model the exponential distribution of the enforcement time may be determined, according to (8).

Finally, for the sake of simplicity the fuzzy operators implementing the fuzzy inference in all the described FIS components are chosen as follows: the minimum as and operator, the maximum as or operator, the minimum as implication method, the center of gravity as defuzzification method.
### Table 7: The data for the simulation experiments.

<table>
<thead>
<tr>
<th>Variables</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>s consulted suppliers number</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>μ average purchasing price (€)</td>
<td>50,000</td>
<td>30,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ&lt;sub&gt;max&lt;/sub&gt; purchasing price standard deviation (€)</td>
<td>10,000</td>
<td>3,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ&lt;sub&gt;max&lt;/sub&gt; supplier maximum preference rate</td>
<td>0.25</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL product/service standardization level</td>
<td>0.25</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SV supply value</td>
<td>0.80</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R supplier reliability</td>
<td>0.70</td>
<td>0.45</td>
<td>0.70</td>
<td>0.45</td>
</tr>
<tr>
<td>p supplier probability of success to provide product/service</td>
<td>0.90</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>P&lt;sub&gt;s&lt;/sub&gt; probability of agreement (drafting and approval)</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c&lt;sub&gt;b&lt;/sub&gt; buyer hour cost (€)</td>
<td>30.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c&lt;sub&gt;c&lt;/sub&gt; lawyer hour cost (€)</td>
<td>150.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c&lt;sub&gt;c&lt;/sub&gt; quality worker hour cost (€)</td>
<td>50.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b&lt;sub&gt;1&lt;/sub&gt; control time Beta distribution characteristic parameter</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ&lt;sub&gt;max&lt;/sub&gt; maximum research time (h)</td>
<td>4.00</td>
<td>2.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ&lt;sub&gt;max&lt;/sub&gt; maximum contact time (h)</td>
<td>8.00</td>
<td>4.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ&lt;sub&gt;max&lt;/sub&gt; maximum negotiation time (h)</td>
<td>24.00</td>
<td>4.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ&lt;sub&gt;max&lt;/sub&gt; maximum drafting and approval of the contract time (h)</td>
<td>36.00</td>
<td>8.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t&lt;sub&gt;Qmax0&lt;/sub&gt; maximum control time for limit case SV=0 (h)</td>
<td>30.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t&lt;sub&gt;Qmax1&lt;/sub&gt; maximum control time for limit case SV=1 (h)</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t&lt;sub&gt;max&lt;/sub&gt; maximum enforcement time (h)</td>
<td>100.00</td>
<td>30.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. The Simulation Experiments and Results

4.1 The Simulation Specification

The theoretical model is synthesized in the software Arena (Kelton et al., 1998). We evaluate the model by simulating several transactions on the basis of data obtained by interviews with a buyer of an industrial company. In particular, the model is tested by means of four experiments, labelled by P1 to P4: the first two simulations are devoted to analyze products with a higher average purchasing price (in particular we select \( \mu_1=\mu_2=50,000 \) €); the remaining two tests analyze the purchasing of goods with a lower average purchasing price (\( \mu_3=\mu_4=30,000 \) €). Moreover, Table 7 shows the input parameters of each simulation. For the sake of clarity, the meaning of each parameter is repeated in the table. As an example, let us analyse the column in Table 7 corresponding to simulation P1. In this test we consider \( s=2 \) consulted suppliers, an average purchasing price of € 50,000 with a maximum standard deviation \( \sigma_{\text{max}}=20\% \) of the purchasing price, i.e. € 10,000, a maximum preference rate for the generic supplier \( \gamma_{\text{max}}=0.25 \), a standardization level of the required product \( SL \) equal to 0.25, a supply value \( SV=0.80 \) and a reliability of the two suppliers \( R \) equal to 0.70 and 0.45, respectively. The probability that these suppliers accept to bid is respectively 0.90 and 0.60 and the probability to reach the agreement is \( P_{Ag}=0.95 \). Moreover, the considered column reports the hour costs for the buyer \( c_B=30 \) €, for the lawyer \( c_E=150 \) € and for the quality control employee \( c_C=50 \) €, respectively. In addition, the characteristic parameter defining the shape of the Beta distribution (7) is \( b_1=1.5 \). Finally, the maximum values of the times required to calculate the transaction costs, are the following: \( t_{R_{\text{max}}}=4.00 \) h (maximum time of research), \( t_{C_{\text{max}}}=8.00 \) h (maximum time of contact), \( t_{N_{\text{max}}}=24.00 \) h (maximum time of negotiation), \( t_{D_{\text{max}}}=36.00 \) h (maximum time of drafting and approval of the contract), \( t_{Q_{\text{max}0}}=30.00 \) h (maximum time of quality control for the limit normalised supply value \( SV=0 \)), \( t_{Q_{\text{max}1}}=100.00 \) h (maximum time of quality control for the limit normalised supply value \( SV=1 \)) and finally \( t_{E_{\text{max}}}=100.00 \) h (maximum time of legal enforcement).

An independent replication method is used to obtain the estimate of the total and transaction cost, with a confidence interval of 95\%. More precisely, for each simulation the cost estimates are deduced by 10,000 independent replications, so that significant results from a statistical point of view are obtained.

4.2 The Results and Discussion

As an example, the transaction and total costs resulting from the simulation labelled by P1 (P3) in Table 7 are respectively shown in Figures 9a (10a) and 9b (10b). The figures depict the obtained cost probability distribution and the average value (represented by a dashed vertical line) for the considered transaction.
Figure 9: The transaction costs (a) and the total costs (b) obtained by simulation P1 ($s=2$, $\mu=50,000$, $SL=0.25$, $SV=0.80$).

Figure 10: The transaction costs (a) and the total costs (b) obtained by simulation P3 ($s=4$, $\mu=30,000$, $SL=0.85$, $SV=0.30$).

Table 8: The results of the simulations.

<table>
<thead>
<tr>
<th>Simulation</th>
<th>$s$</th>
<th>$\mu$</th>
<th>$SL$</th>
<th>$SV$</th>
<th>$C_T$ [€]</th>
<th>$C_T+P_r$ [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2</td>
<td>50,000</td>
<td>0.25</td>
<td>0.80</td>
<td>10,001.12</td>
<td>57,978.77</td>
</tr>
<tr>
<td>P2</td>
<td>4</td>
<td>50,000</td>
<td>0.25</td>
<td>0.80</td>
<td>10,669.56</td>
<td>55,807.45</td>
</tr>
<tr>
<td>P3</td>
<td>4</td>
<td>30,000</td>
<td>0.85</td>
<td>0.30</td>
<td>3,574.24</td>
<td>32,879.04</td>
</tr>
<tr>
<td>P4</td>
<td>8</td>
<td>30,000</td>
<td>0.85</td>
<td>0.30</td>
<td>3,864.66</td>
<td>32,655.20</td>
</tr>
</tbody>
</table>

The transaction costs and total costs resulting from the four considered simulations are reported in Table 8. In order to improve readability, the table also reports the number of considered suppliers $s$ in the corresponding transaction, the average purchasing price $\mu$, the normalised standardization level $SL$ and the supply value $SV$ of the transaction. Hence, the simulations consider the four kinds of products, i.e. P1 to P4, mainly characterized by a difference in the level of information flows for the purchasing process and the amount of risk. Observing the results in Table 8, we remark that transaction costs may be a little part of the total costs (about 11%) for products P3 and P4, characterized by a high standardization level and a low supply value. On the contrary, transaction costs represent a more relevant percentage of the total costs (about 20%) in the case of products P1 and P2, both characterized by a low standardization level and a high supply value. In addition, the results in Table 8 confirm that customized products (i.e. P1 and P2) require higher total costs than standardized goods (i.e. P3 and P4). Moreover, the obtained
simulation results reported in Table 8 show that, as the number of consulted suppliers increases, transaction costs increase accordingly. However, as the number of suppliers is raised, the probability to get a lower purchasing price increases accordingly (compare the results for P1 and P2 and for P3 and P4 in Table 8). Obviously, such a phenomenon is more noticeable in the case of a customized product (e.g. consider P1 and P2 in Table 8).

5. Conclusions
The paper proposes an approach to estimate the transaction costs connected to the exchange of a new product/service before the transaction is actually carried out, so that a decision support system for the buyer is available. The problem is addressed by proposing a model for the buyer/seller relationship, that focuses on the uncertainty characterizing the exchange and the connected costs. In particular, based on a well-known classification, the transaction costs are determined using appropriate deterministic models for \textit{ex ante} costs and suitable statistical distributions for \textit{ex post} costs. Moreover, a fuzzy logic inference system is designed for synthesising, starting from expert judgments, the required data to the transaction costs model. We evaluate the model by simulating several transactions on the basis of data obtained by interviews with a buyer of an industrial company. The reported simulation experiments show the effectiveness of the proposed model in estimating the transaction costs and total costs associated with a generic purchasing process. Moreover, the obtained results show the interesting connections of transaction and total costs with the total number of suppliers and the product standardization level. The model can be used to determine the optimal number of suppliers to be consulted when a new product is requested from the buyer, i.e. the number of buyers that balances the pressure exercised by transaction costs (which increase with the number of suppliers) and the one exercised by the purchasing price (which decreases with the number of suppliers).

6. References

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