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# A reputation based electronic government procurement model

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ABSTRACT

Each year, governments spend billions in procurement. In this context, they generally select their suppliers based on the minimum price. However, other criteria than price may be considered to help governments minimize the procurement costs. This paper proposes a formal reputation model that is intended to determine the winners of a public procurement process. The proposed model combines three elements: (1) the direct reputation of the supplier, (2) the indirect reputation of the supplier, and (3) the difference in beliefs between the government and the supplier. The proposed model compares situations where reputation is integrated along price for selecting suppliers and where it is not. Results show that the proposed reputation model may lead to lower costs for governments.



## 1. Introduction

E-government aims at making the interactions between the government and citizens (G2C), the government and businesses (G2B), and inter-agency relationships (G2G) more cooperative, convenient, and transparent (Mellouli & Bouslama, 2009), (Chourabi & Mellouli, 2011). It should lead to better delivery of services to citizens, improved interactions with businesses and industries, less corruption within governmental agencies, increased transparency, greater convenience, higher revenue growth, and finally cost reduction (Schelin, 2003), (Davison, Wagner, & Ma, 2005), (Affisco & Soliman, 2006). This paper focuses on G2B relations specifically in the case of public procurement.

Public procurement is the process by which governmental agencies acquire goods, services and works from third parties. Governments may adopt different regulations for procurement processes that can range from selective outsourcing to large outsourcing deals (Cordella & Willcocks, 2012). For example in Canada, there are two types of public procurement processes: competitive procurement process (large outsourcing) and non-competitive procurement (selective outsourcing) process. The calls for competitive or non-competitive processes depend on the value and the type of contracts (Canadian Government, 2015). The Government of Canada spends more than 16.05 billion dollars of purchasing per year(Canadian Government, 2015). However, and as stated in (Cordella & Willcocks, 2012), it is not always ensured that outsourcing activities to third parties will be successful. For example, in the case of Information Technology (IT) projects in the United Kingdom, one in eight IT projects was a failure considering time, cost, and specification (UK Government, 2003). These failures are not only the responsibility of governments but they are shared with supplying companies. Hence, by participating in different projects that can end by either a success or a failure, a company can build its own reputation: is it a 'good' or a 'bad' supplier? Generally, governments would prefer to work with 'good' companies. This paper is a first attempt to provide a model to compute the reputation of a company so that governments can work with 'good' ones with the objective to decrease the number of failed publically-funded projects.

The objective of this paper is to propose a formal reputation model for determining the winners of an e-government procurement based on both the price and the suppliers' reputations. We propose to compute the reputation of a supplier by combining three elements: (1) the direct reputation, (2) the indirect reputation, and (3) the difference in beliefs, and taking into account five parameters: (a) the negotiation field, (b) the arrangement weight, (c) the arrangement time, (d) the reliability degree, and (e) the importance degree of the supplier.

An exhaustive experimental study is conducted to outline the potential gains that could be obtained by using the proposed reputation model when compared to the case where only bidding prices are taken into account. Our study considers the particular case of transportation procurement where a governmental agency sends a request for proposals (*RFP*) to select a set of carriers to ensure some of its transportation operations (for example, transport of recyclable materials). We

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also investigate the impact of adding knowledge on the government total expected cost by considering different alternatives when computing the carrier reputation. Finally, we analyse different situations to take into account the behaviour of the governmental agency with regard to risk. In other words: should a government agency always contract with suppliers with which it has a good past relations with or should it open the bids to "new" suppliers with which it has no past relations?

The paper is organized as follows. Section 2 presents a literature review on the reputation in public procurement. Section 3 identifies the three elements and the five parameters used to build the reputation model. It describes the proposed formal reputation model. Section 4 presents the experimental results. Section 6 discusses the possibility of integration of reputation systems in the e-government procurement system. This section concludes the paper and opens on future research directions.

## 2. Reputation and public procurement: literature review

Public procurement is an integral part of G2B processes (Panayiotou, Gayialis, & Tatsiopoulos, 2004), (Teo, Devadoss, & Pan, 2006) and it is a procedure that allows governments to operate efficiently. In a public procurement process, the government sends a *RFP* to different suppliers and waits for their replies. When it receives the procurement responses, a negotiation process is started with the interested suppliers. Through public procurement, a government aims to find a good combination of suppliers for the acquisition of commodities or services while the objective of the suppliers is to win the *RFP* with maximum profits (Garrido, 2008), (Concha, Porrúa, & Pimenta, 2010).

Winning suppliers can take advantage from a collaboration with government agencies since they can build their own image; they can have access to additional resources, benefit from a lower bureaucratic bunder, and improve their reputation in the market (Vinogradov, Shadrina, & Kokareva, 2014). Hence, one of the main elements that can impact a company operations is its reputation. Reputation can guarantee to companies long term contracts with governments (Vinogradov et al., 2014). Consequently, from these statements, suppliers have to maintain a good reputation in a public market in order to have chances to acquire new contracts with government agencies. However, a question remains: does reputation lead to better procurement results for the public sector? To the best of our knowledge, reputation has not yet been formally considered in the decision making process of public procurements. However, reputation has been tested in other disciplines, such as auctions, to show how it can improve final outcomes. Reputation allows the prediction of the entities that can be trusted for future transactions based on the feedback from the pasts transactions (Hendrikx, Bubendorfer, & Char, 2015).

Different research works have been conducted in order to show the importance of considering the reputation of a supplier along with the price in order to determine the winner of an auction (Sabater & Sierra, 2005), (Jiang, Xia, Zhong, & Zhang, 2005), (Indiramma & Anandakumar, 2008), (Lopes, Wooldridge, & Novais, 2008), (Bentahar, Khosravifar, & Gomrokchi, 2009). The reputation can be either used in a pre-procurement phase, to select the suppliers that can participate in the procurement process, or in the procurement process to determine winning suppliers. Noorian and Ulieru (2010) showed that open electronic marketplaces and on-line collaboration systems require the establishment of mutual trust between service providers and service consumers. The authors showed that to address these concerns, reputation systems can be used to evaluate the reliability and credibility of the participants such that recommendation can be made when needed.

In order to build a reputation system for public procurement, and with the absence of studies in this context, we looked at other studies that considered reputation and we tried to adapt these models to public procurement. In the literature, to determine the reputation of a supplier, two mains elements are generally considered: the direct, and the indirect reputations (Malik & Bouguettaya, 2009), (Denko & Woungang, 2011). The *direct reputation* uses the past arrangements concluded between a service provider *S* (supplier) and a service consumer *G* (government agency in our context) (Xiong & Lui, 2004), (Denko & Woungang, 2011). The arrangements are classified into two types: satisfied ones and unsatisfied ones (Sabater & Sierra, 2001b), (Wang & Vassileva, 2003). If the number of satisfied arrangements is greater than the unsatisfied ones, *G* considers *S* as having a good direct reputation (Malik & Bouguettaya, 2009), (Khosravifar, Gomrokchi, Bentahar, & Thiran, 2009). The *indirect reputation* refers to the direct reputation of service provider *S* as estimated by third-party service consumers that are called the witnesses agents (Wang & Vassileva, 2003), (Tafreschi, Mähler, Fengel, Rebstock, & Eckert, 2008). The indirect reputation helps *G* to have a better idea on *S* (Xiong & Lui, 2004), (Jiang et al., 2005), (Khosravifar et al., 2009). In the context of this paper, the witnesses can be other governments agencies at different government levels. *G* will combine the direct reputation of *S* with the indirect reputations that it will collect from others in order to define a global reputation of S.

## 3. Reputation model

Fig. 1 presents a general architecture that can be implemented to build a reputation-based e-procurement system in which a governmental agency (*G*) has to select suppliers to ensure a number of services. In the proposed architecture, each component has a specific role as described in what follows:

Governmental Agency (*G*): Let *G* be a government agency at any government level (federal, provincial, or municipal). *G* sends a *RFP* to different suppliers and wait for replies from those who are interested. The objective of *G* is to find a good combination of suppliers to fulfill its needs.

Suppliers (*S*): Several suppliers are invited to participate in the government procurement process. Each supplier submits its offers to *G* through the communication layer.

Witness governmental agencies (*WG*): To have a good idea on the participating suppliers, *G* may be assisted by a set of *WGs*. Based on its historical data, each *WG* sends to *G* its opinion with regard to the suppliers.

Reputation based e-procurement system: The reputation based e-procurement system is the mechanism for determining the winning suppliers. The selection process is based on the price and the suppliers' reputation.

This paper proposes to compute the reputation of a supplier by combining three components: (1) the direct reputation, (2) the indirect reputation, and (3) the difference in beliefs. As discussed in Section 2, direct and indirect reputations have already been considered in the literature and different approaches have been presented to evaluate them. This paper proposes an innovative approach to compute direct and indirect reputations that considers five parameters already proposed in the literature for specific contexts but were never integrated in the same direct/indirect reputation model. Considering all these parameters enables to define more realistic, relevant and reliable e-procurement systems. In addition, the proposed reputation model considers the *difference in beliefs* component that has, and to the best of our knowledge, never been used to compute reputation.

### 3.1. Direct reputation

The direct reputation of a supplier is generally computed from the previous arrangements contracted with that supplier. These arrangements are classified into two types: satisfactory and unsatisfactory. In (Khosravifar et al., 2009), the direct reputation is computed based on the ratio of the number of satisfactory arrangements by the total number of arrangements. More precisely, a beta expectancy formula is proposed so that when the number of satisfactory arrangements is greater than unsatisfactory ones, the beta expectancy is close to 1. In this paper, we propose an innovative way to compute the direct

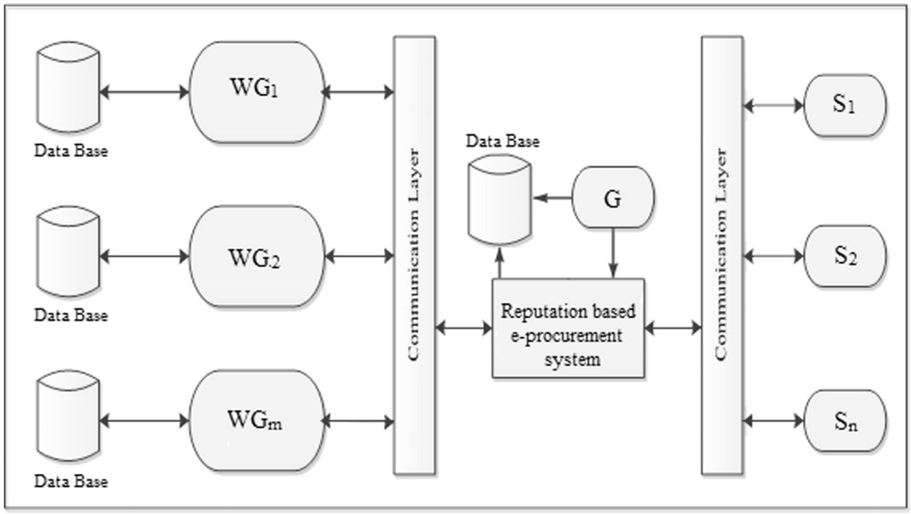


**Fig. 1.** General Architecture of the reputation-based e-procurement system.

reputation using a formula inspired by the beta expectancy but in which the number of satisfied and unsatisfied arrangements is adjusted based on three parameters, namely: the negotiation field, the time of arrangement and the weight of arrangement. The beta expectancy value is then "corrected" using a fourth parameter: the so-called direct reliability degree parameter.

The negotiation field represents the influence of the procurement domain and is an important parameter to consider (Carley, 1999), (Haghpanah & desJardins, 2010), (Denko & Woungang, 2011). For example, in transportation procurement processes, transporting toxic or inflammatory products may be considered as more important than transporting furnitures. In the proposed model, it is assumed that $G$ has already assigned a negotiation field value $NF(h)$ -ranging from 0 to 1- to each past arrangement $h$ it had with each participating supplier.

The time of past arrangements is widely considered in the literature dealing with reputation (Huynh, Jennings, & Shadbolt, 2006), (Haghpanah & desJardins, 2010), (Huang, Liang, Lai, & Lin, 2010). In our context, this implies that $G$ has to weight the past arrangements with regard to the time when they occurred; recent arrangements having greater weight than the past ones.

We propose to compute this weight using the exponential function proposed in (Huynh et al., 2006) since it helps adapt quickly to any changes in a supplier performance over time. In the following, the time of past arrangements parameter associated with a past arrangement $h$ is denoted $TA(h)$. We refer the reader to the appendix for a formal description of the formula used to compute $TA(h)$.

The weight of arrangement parameter suggests that a government agency $G$ should give greater weights to the arrangements that have led to more economic savings. The weight of arrangement parameter associated with a past arrangement $h$ is denoted by $WA(h)$. We refer the reader to the appendix for a formal description of the formula used to compute $WA(h)$.

Based on these three parameters, the adjusted number of satisfactory and unsatisfactory arrangements contracted in the past to supplier $s$ by $G$ is given by:

$$N'_{Sat}(G,s) = \sum_{h \in H_{Sat}(G,s)} NF(h) * TA(h) * WA(h)$$
$$N'_{U\,Sat}(G,s) = \sum_{h \in H_{USat}(G,s)} NF(h) * TA(h) * WA(h)$$

where, $H_{Sat}(G,s)$ and $H_{USat}(G,s)$ represent respectively the set of satisfactory and unsatisfactory arrangements contracted in the past to supplier $s$ by $G$.

Furthermore, in order to have a good assessment of the supplier reputation, we propose to adjust the beta expectancy formula by using the so-called direct reliability degree parameter. A reliability degree is based on the principle that the judgment that a government agency $G$ can have about a supplier depends on the number of arrangements that $G$ has with the supplier (Sabater & Sierra, 2001a), (Barouni, Ait-Kadi, Mellouli, & Ruiz, 2009), (Malik & Bouguettaya, 2009). In this formula, the direct reliability degree is a value comprised between 0 and 1. The value is less than 1 if the number of arrangements is less than a certain minimum. The value is 1 if the number of arrangements is greater than this minimum. In our case, we propose to compute the direct reliability degree by considering the formula proposed in (Sabater & Sierra, 2001a). The direct reliability degree associated with $G$ and supplier $s$ is denoted $\xi_d(G,s)$. We refer the reader to the appendix for a formal description of the formula used to compute $\xi_d(G,s)$.

Hence, the direct reputation of supplier $s$ with regard to $G$ is computed as follows:

$$R_d(G,s) = \xi_d(G,s)\left(\frac{N'_{Sat}(G,s)+1}{N'_{Sat}(G,s)+N'_{U\,Sat}(G,s)+2}\right) \tag{1}$$

### 3.2. Indirect reputation

As presented in Fig. 1, the governmental agency $G$ running the e-procurement process may ask other governmental agencies (the witness agencies $WGs$) about the reputation of supplier $S$. The information sent by $WGs$ is then used to compute the so-called indirect reputation of supplier $s$. We propose to compute this indirect reputation based on three parameters: the time of knowledge, the importance degree, and the indirect reliability degree.

The time of knowledge parameter is intended to give more weight to recent knowledges than past ones. In fact, the behavior of a supplier may change and evolve over time by either improving or decreasing the quality of its services. The intuition behind the time of knowledge is to weight the behavior of a supplier over time by giving more importance to recent behaviors than past ones. We propose to compute the time of knowledge using the formula proposed by (Huynh et al., 2006). The time of knowledge parameter associated with witness agency $WG$ and supplier $s$ is denoted $\Gamma(WG,s)$ in the following. We refer the reader to the appendix for a formal description of the formula used to compute $\Gamma(WG,s)$.

The importance degree parameter enables the governmental agency $G$ to adjust the information given by a witness agency $WG$ on a supplier $s$

reputation depending on its level of knowledge of $s$ (Barouni et al., 2009). The objective is to give larger weights to witness government agencies that know more the supplier $s$. As in (Barouni et al., 2009), the level of knowledge of the witness agent $WG$ of the supplier $s$ is computed as the ratio between the number of past arrangements made by $WG$ with supplier $s$ and the total number of past arrangements made by $WG$. The importance degree of witness agent $WG$ with regard to supplier $s$ is denoted $\theta(WG,s)$. We refer the reader to the appendix for a formal description of the formula used to compute $\theta(WG,s)$.

Besides, we remind that the direct reliability degree parameter enables the government agency $G$ to adjust its own information about a supplier $s$ based on the number of past arrangements contracted with it. Here, we apply the same idea to define the so-called indirect reliability degree parameter but with respect to the volume of information available from other witness government agencies $WG$ on the supplier $s$. This indirect reliability degree is denoted $\xi_{ind}(G,s)$ in the following. We refer the reader to the appendix for a formal description of the formula used to compute $\xi_{ind}(G,s)$.

Finally, we propose to compute the indirect reputation of supplier $s$ with respect to $G$ in two steps. In the first step (the pre-selecting step), the governmental agency $G$ may decide to not consider any information from a witness agency $WG$ with regard to $s$, if the corresponding importance degree $\theta(WG,s)$ is smaller than a threshold value $\theta^*$ pre-fixed by $G$. Doing so, $G$ decides to consider only witnesses that may impact its perception of the supplier. In the second step, the governmental agency $G$ combines all accepted information and computes the indirect reputation $R_{ind}(G,s)$ of the supplier $s$ as follows:

$$R_{ind}(G,s) = \xi_{ind}(G,s)\left(\frac{\sum_{WG \in WG(s)} \theta(WG,s)\Gamma(WG,s)R_d(WG,s)}{\sum_{WG \in WG(s)} \theta(WG,s)\Gamma(WG,s)}\right) \quad (2)$$

where $WG(s)$ denotes the set of witness agencies that are retained after the pre-selecting step.

### 3.3. Difference in beliefs

The *difference in beliefs*, introduced in (Castelfranchi & Falcone, 1998), allows a G to check the accuracy of the offer received from a supplier. We assume that the request for *RFP* presented by $G$ is composed of a set of criteria $p$ to which participating suppliers respond by submitting offers. Let $DB(G,c,s)$ denote the difference in beliefs between $G$ and supplier $s$ with regard to criterion $c$. A criterion can have either qualitative or quantitative values. For example, a supplier proposes the price (qualitative criterion) of 300 dollars for a given service. However, if $G$ believes that the price of such service should not exceed 100 dollars, it may then conclude that the supplier is unreliable. In the case of a qualitative value, for example a supplier proposes a product as excellent and $G$ considers it as good. This also constitutes a difference in beliefs between $G$ and its supplier. We refer the reader to the appendix for a formal description of the formula used to compute $DB(G,c,s)$ in both quantitative and qualitative cases. The difference in beliefs of the supplier $s$ with regard to $G$ for the current *RFP* is given by:

$$DB(G,s) = \sum_{c=1}^{p} w_c DB(G,c,s) \quad (3)$$

where $w_c$ is the weight given by $G$ to criterion $c$, $w_c \geq 0$, and $\sum_{c=1}^{p} w_c = 1$. The government agency can determine the weights to give to a criterion with regard to its importance in a decision-making process of the agency. For example, the agency can consider a criterion as more important than another criterion because the information that the first criterion provides is more important than the information provided by the second criterion.

The reputation $R(G,s)$ of supplier $s$ with regard to government agency $G$ is computed as follows:

$$R(G,s) = \beta_1 R_d(G,s) + \beta_2 R_{ind}(G,s) - \beta_3 DB(G,s). \quad (4)$$

where, $\beta_1$, $\beta_2$, and $\beta_3$ represent respectively the weights associated with direct reputation, indirect reputation, and difference in beliefs; $\beta_i \geq 0, \forall i = 1, \ldots, 3$ and $\sum_{i=1}^{3} \beta_i = 1$. These weights are defined by the government agency to model the importance of each component. The value of each component (direct reputation, indirect reputation, and difference in beliefs) is between 0 and 1. A supplier is considered reliable when its corresponding direct and indirect reputations lean towards 1 and its corresponding difference in beliefs leans towards 0.

The reputation model presented above computes direct and indirect reputations of a supplier $s$ as a whole without going into details on the criteria judged important by $G$ in the supplier evaluation process. It is worth mentioning that the proposed model can be easily extended to the case where a number of attributes are considered to evaluate suppliers' reputations by simply defining the direct and indirect reputations by attributes.

## 4. Experimental study

The objective of the experimental study is threefold. First, we want to asses the importance of considering suppliers' reputation in an e-government procurement system. This is done by computing monetary savings that could be possibly achieved by $G$ compared to the case where the lowest price is taken as the sole criteria to select winning suppliers. Second, we want to investigate the impact of adding knowledge on solution quality. This is done by gradually incorporating the reputation components in the reputation formula and measuring the additional savings in each case. Third, we want to study the impact of $G$ behaviour with regard to risk on the potential savings/losses that could be obtained. This is done by comparing the total costs incurred by $G$ in cases $G$ is risk-averse, risk-seeking and risk-neutral.

Our study represents a theoretical simulation that considers the particular case where $G$ faces the problem of selecting carriers to outsource a number of transportation services. The objective of $G$ is to determine the winning carriers (suppliers) based on both ask-prices and carriers reputation. The transportation procurement process studied is described in more details in the next section.

### 4.1. Transportation procurement process

We consider the case in which a government agency $G$ is asking suppliers to send bids for a transportaton service. The auction process can briefly be described as follows. The government agency $G$ first submits its transportation requests to the market. A transportation request, also called a contract, is defined by pick-up and delivery locations, delivery frequency (daily, weekly, monthly), particular equipments, etc. The set of all transportation contracts required by $G$ is denoted $K$. Each participating carrier then submits a set of bids on the set of contracts it is interested in. A bid $b$ is defined by a couple $(K_b, BP_b)$, where $K_b \subseteq K$ is the set of contracts the carrier offers to ensure in its bid $b$ and $BP_b$ is the price asked for serving all the contracts in $K_b$. After receiving all carriers' bids, $G$ solves the so-called Winner Determination Problem (WDP) to determine winning carriers. The WDP is modelled and solved using mathematical programming techniques. The explicit mathematical formulation is presented in the appendix.

As in (Rekik & Mellouli, 2012), we propose to solve the WDP based not only on bid prices but also on carriers' reputation. Our approach for computing reputation largely extends that proposed in (Rekik & Mellouli, 2012) since it incorporates the indirect reputation and the difference in beliefs components and proposes new realistic parameters to compute the direct reputation component. As in (Rekik & Mellouli, 2012), $G$ is assumed to evaluate the reputation of a carrier with regard to three attributes: on-time delivery ($\omega_1$), percentage of damages ($\omega_2$), and percentage of cancellations ($\omega_3$). Roughly speaking, the on-time delivery attribute reflects the ability of the carrier to satisfy the delivery time interval imposed by *G*. The percentage of damages attributes shows the ability of the carrier to keep the quality of the shipped commodities. Finally, the cancellation attribute gives an idea on the ability of the carrier to respect its engagements to serve all the attributed shipments. We adapted formula (1) to compute the reputation associated with each attribute. For example, for the attribute "on-time delivery", we consider the satisfactory arrangements as those where the deliveries were on time.

The way reputation is used to solve the reputation-based WDP remains the same as in (Rekik & Mellouli, 2012) through considering "hidden costs". Indeed, the authors propose to quantify the reputation of a carrier with regard to an attribute $\omega_i; i = 1, 2, 3$ as a potentially additional cost to be paid by the shipper (in addition to bid ask price) given the reputation of the carrier for this attribute. We refer the reader to (Rekik & Mellouli, 2012) for more details on hidden costs. In our case, we associate two types of hidden costs to a bid *b* submitted by a carrier *s*: one for the carrier *s* direct reputation, denoted $HC_d(s,b)$, and one for its indirect reputation, denoted $HC_{ind}(s,b)$. The explicit formulations used to compute these direct and indirect hidden costs are presented in the appendix.

### 4.2. Problem tests

Our tests are built by varying a number of key parameters, namely: the number of contracts $|K|$, the number of bids $|B|$, the number of carriers $|S|$, the number of past arrangements $|H|$, and the number of *WGs* recommendations $|R|$. Bid generation uses the CATS generator -proposed by (Leyton-brown, Pearson, & Shoham, 2000)- as a black box to which we passed as input the number of contracts ($|K| = 20, 40, and\ 60$) and the number of bids ($|B| = 100, 120, \text{and } 180$). Then, a number of carriers $|S|$ (set equal to $\frac{|B|}{10}$ and $\frac{|B|}{5}$) is considered and bids are randomly assigned to the carriers. Finally, the number of recommendations from *WG* is set equal 50,100, and 150, and the number of past arrangements to $= 1000, 2000$, and 3000. A total of 600 instances are generated, 100 instances for six procurement contexts ($|K|, |B|, |S|, |H|, |R|$).

Four scenarios are considered and compared. These scenarios differ from one another on the objective function that is considered when solving the WDP.

1. Scenario 1 (Classic case): the winners of the procurement auction are determined using only the bid ask-prices.
2. Scenario 2 (Direct Reputation): the winners of the procurement auction are determined using the bid asked-prices and the direct reputation.
3. Scenario 3 (Direct Reputation and Difference in Beliefs): the winners of the procurement auction are determined using the bid asked-prices and the reputation computed based on the direct reputation and the difference in beliefs. Observe that the difference in beliefs component is modelled as a percentage increase in the bid price so that bids with large difference in beliefs values are not selected.
4. Scenario 4 (Global Reputation): the winners of the procurement are determined using the bid asked-prices and the reputation computed based on the direct reputation, the indirect reputation, and the difference in beliefs

   The objective functions of the four scenarios are explicitly given in the appendix.

### 4.3. Impact of considering suppliers' reputation on procurement outcomes

This section considers scenarios 1 and 4. The objective is to evaluate the relative saving/loss obtained with a reputation-based WDP model- as proposed in this paper- with respect to bid-price-oriented WDP. A number of performance measures are computed and compared, which are: the direct cost (the cost to be paid by *G* to the winning suppliers as asked in their winning bids), the hidden costs (the costs that would potentially be paid by *G* given the supplier's reputation), and the total transportation costs (which is the sum of the direct and hidden costs). We also report the percentage of carriers substitution (PCS) to give an idea on the level of change in winners identity between both scenarios.

Table 2 (Appendix B.5) reports for each performance measure, the average percentage saving/loss ("AV") over the 100 of each procurement context ($|K|, |B|, |S|, |H|, |R|$) and the corresponding standard deviation (SD). A percentage saving/loss for an instance *i* and a performance measure *PM* is computed as:

$$\frac{P^4(PM,i) - P^1(PM,i)}{P^1(PM,i)} * 100 \tag{5}$$

where $P^1(PM,i)$ is the value of the performance measure *PM* with scenario 1 for instance *i* and $P^4(PM,i)$ its value for scenario 4. Observe that for scenario 1, the direct and indirect hidden costs are computed a posteriori once the winning bids are determined based only on ask prices. Hence, when the value in Eq. (5) is negative this means that scenario 4 performs better than scenario 1 for the corresponding performance measure.

The results of Table 2 show that scenario 1 always generates direct costs that are lower than those obtained with scenario 4. This result was expected since scenario 1 selects carriers that minimize only the total bid ask price. The average increase in bid prices for scenario 4 ranges between 5.32% and 9.64%. The opposite behaviour is observed for total hidden costs (the lowest values are always obtained with scenario 4). This was also predictable given the objective function of the WDP considered in scenario 4. However, it is clear from Table 2 that the saving in hidden costs is much more important in scenario 4 versus scenario 1 (up to 58.11%) against a relatively smaller increase in direct costs (no more than 9.64%) yielding a saving in total transportation costs for all the instances that reaches 5.72%.

Hence, although considering reputation may yield an increase in the direct costs, a significant saving in the total transportation costs can be achieved when the reputation of suppliers is considered.

### 4.4. Impact of adding knowledge on procurement outcomes

The object of this section is to investigate the impact of adding knowledge on the selection process and on the total costs incurred by *G*. First, we evaluate the impact of considering only the direct reputation component when considering the carriers' reputation. To this end, and as in Table 2, we report the relative saving/loss in direct, hidden and total procurement costs obtained with scenario 2 with regard to scenario 1. The results are displayed in Table 1 (Appendix B.5). In this table, a negative value implies that scenario 2 (with direct reputation) yields a saving and a positive value implies a loss in Scenario 2 with respect to 1. Then, we consider the case where the difference in beliefs component is taken into account in addition to the direct reputation to compute the carrier reputation (scenario 3) and compare scenario 3 to scenario 2. The obtained results are reported in Table 3 (Appendix B.5). A negative value in Table 3 means that scenario 3 performs better. Finally, we consider the case where the indirect reputation is considered together with the direct reputation and the difference in beliefs to compute reputation (scenario 4). We compare the costs obtained for scenario 4 to that of 3. The results are displayed in Table 4 (Appendix B.5). A negative value in this table implies that scenario 4 performs better than scenario 3.

It is noteworthy that the way a posteriori hidden costs are computed differs from one table to another depending on the components considered in the compared scenarios. More precisely, in Table 1 (Appendix B.5), the hidden cost of Scenario 1 is computed a posteriori by considering only the direct reputation component. In Table 4, the hidden cost considered for comparison for Scenario 3 is the sum of the direct hidden cost as obtained when solving the WDP of scenario 3 and the a posteriori indirect hidden cost.

The results of Table 1 show that the integration of direct reputation leads to important savings in hidden costs and total transportation costs. The average saving in hidden cost ranges from 15.44% to 35.02% and in total transportation cost from 0.58% to 2.66%. In other words, even if the government agency wants to (or can) consider only its own knowledge to evaluate a supplier reputation, it has interest to consider it in the selection process.

The results of Table 3 (Appendix B.5) show that considering the difference in beliefs component yields important saving in both direct costs (up to 12.64%) and direct hidden costs (up to 8.33%) when compared to the case where only the direct reputation is used (scenario 2). This is explained by the fact that in scenario 2, the governmental agency would select a bid as long as the carrier offering it has a good direct reputation even if the corresponding ask price is inflated. Considering the difference in beliefs component enables avoiding such situations and offers a better trade-off between direct reputation and bid ask prices.

The results of Table 4 (Appendix B.5) clearly prove that exchanging information with other governmental agencies (i.e., taking into account the indirect reputation) helps adjust the reputation of carriers and results in gains at the direct cost (between 1.36% and 5.78%, on average), the hidden costs (between 1.61% and 8.82%, on average) and the total costs (between 2.74% and 5.18%) levels. In other words, a bid with a relatively low ask price may have not won in scenario 3 because the direct reputation of the carrier submitting is bad (based only on the government knowledge of the carrier). But, by incorporating the indirect reputation component, the carrier reliability is adjusted and the bid wins in scenario 4.

### 4.5. Impact of G's risk behaviour on procurement outcomes

The proposed reputation model can be used to model the behaviour of *G* with regard to risk by tuning the values of the direct reputation, indirect reputation and difference in beliefs weights ($\beta_1, \beta_2, \beta_3$). Roughly speaking, a risk-seeking *G* tends to deal with either new carriers or carriers with which it had not a very good experience. In our case, this can be modelled by attributing a weight for the direct reputation component that is relatively smaller than the weight used for the indirect reputation component.

Three *G* behaviours are considered and the corresponding weights fixed as follows:

1. Risk-neutral behaviour: $\beta_1 = 0.35$, $\beta_2 = 0.35$, and $\beta_3 = 0.3$.
2. Risk-averse behaviour: $\beta_1 = 0.6$, $\beta_2 = 0.1$, and $\beta_3 = 0.3$.
3. Risk-seeking behaviour: $\beta_1 = 0.1$, $\beta_2 = 0.6$, and $\beta_3 = 0.3$

The reputation-based WDP (scenario 4) is then solved three times for each instance, one time for each combination of the $\beta$ values. The three performance measures (direct cost, hidden cost, and total cost) are compared for each pair of behaviours. We then report the gain/loss in percentage obtained for each performance measure when considering: (1) a risk-seeking behaviour versus a risk-neutral one (Appendix B.5–Table 5), (2) a risk-averse behaviour versus a risk-neutral one (Appendix B.5 - Table 6), and (3) a risk-seeking behaviour versus a risk-averse one (Appendix B.5–Table 7).

First, observe that in Table 5, a negative value implies that a risk-seeking behaviour yields better results than a risk-neutral one. The results of Table 5 show that a risk seeking behaviour could be beneficial in some but not all the cases. However, the average saving in total cost with regard to a risk-neutral behaviour reaches 10.17% where the loss does not exceed 2.15%. This implies that for the instances considered, it seems more advantageous for *G* to be risk-seeking than risk-averse. Given the way we model risk-seeking behaviours, this reduces to saying that *G* has interest in taking the opinions of the other governmental agencies on the suppliers even if they do not perfectly match its own opinion.

In Table 6, a negative value implies that a risk-averse behaviour yields better results than a risk-neutral one. The results of Table 6 show that by being too cautious, *G* may miss a good opportunity to make important savings. A risk-averse behaviour may indeed lead to important losses in hidden and total costs when compared to a risk-neutral behaviour. This loss reaches 45.71% in hidden costs and 7.83% in total costs. Even if a risk-averse behaviour may be advantageous in some cases, the gain it yields with respect to a risk-neutral behaviour remains relatively small (no more tha 1.62%).

Obviously, the results obtained in Table 7 do not go against the observations made through analysing Tables 5 and 6. They clearly show that a risk-seeking behaviour may yield considerable savings in some cases when compared to a risk-averse behaviour. This gain reached 68.51% on average in hidden costs and 16.63% in total costs (see the fourth context). The risk-averse behaviour yields savings for three contexts but they remain small comparatively to those resulting from a risk-seeking behaviour.

Our analysis of the impact of the risk-behaviour on the procurement outcomes clearly shows that, for the instances considered, *G* has interest in taking into account the indirect reputation component to adjust the opinion it had on the participating suppliers. Even if being risk-seeking may yield monetary losses in some cases, this loss remains considerably small than the gain it may yield in other cases.

## 5. Discussion and conclusion

This paper focused on public procurement in which the concept of reputation was introduced to help governments select "good" suppliers. This study was applied to simulate the process of externalizing the transportation services of a government to suppliers. A novel model was proposed for determining the winning suppliers by ensuring a trade-off between proposal asked-prices and suppliers' reputations. This model can provide the basic tools for governments in order to evaluate the received bids from suppliers and to guarantee dealing with reliable ones (having the best reputation) and, consequently hoping to minimize the total cost that a government could pay during the externalization of its operations. The supplier reputation is based on the direct reputation, the indirect reputation, and the difference in beliefs. The proposed model is facing different challenges that have to be addressed if such a solution has to be implemented. Indeed, this reputation system has to be integrated within existing public procurement systems currently used by governments. Hence, it is very important to figure out how these systems using reputation can be integrated within existing public procurement solutions. It is important to mention that the basic ingredient to the success of the implementation of this system is that government agencies exchange data about suppliers.

The success of a procurement system requires efficient processes at both the internal workflow and the supplier-purchaser relationship (Teo & Tan, 1998), (Teo, Lin, & Lai, 2009). Hence, the integration of a reputation model within a public procurement system may require changes at both internal workflow and the relationship between the government and its suppliers. More specifically, the reputation is computed based on historical collected data. Hence, governments need to collect specific data about bidding suppliers depending on the type of the procurement. In fact, suppliers' reputations can be computed differently from a procurement to another since different parameters, depending on the type of procurement, can be used. For example, in some cases the delay can be a very important criteria, in others it can be the reliability. So, a unique set of criteria does not exist that can be used to compute the reputation of suppliers for any procurement. The

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latter represents a unique context and requires specific quality parameters to compute the reputation of each suppliers. In addition, as depicted in Fig. 1, governments, from different orders, should exchange data about suppliers. However, the uniformity of the parameters used by government levels, for each type of projects, in order to compute reputation of suppliers is not guaranteed. This leads to complexities in exchanging data between government levels. This issue can also be considered as an interoperability issue between government levels. Solutions based on ontologies can be imagined in order to link different data sets saved in different formats and in different structures. Finally, introducing this reputation model as a new rule for determining the winners of a procurement requires changing the laws governing public procurement. Changing a law is a complex and political task and require that the government discusses the issue with different stakeholders.

Besides the aforementioned issues, there are others that have to be considered when introducing reputation within government procurement systems. First, government agencies may be biased toward a specific supplier; that is they have a preference for this supplier. In this case, reputation can be used in order to provide decision makers with a clear view of the reputation of the biased supplier. Hence, if this supplier doesn't have a good reputation, decision makers can decide to change the supplier and consequently improve the use of public money. Second, there is an issue of the cold-start problem, that is when new suppliers with no historical data will take part in an e-procurement process. It is also noteworthy that the set of participating suppliers may include new ones with which the government has no past direct or indirect experiences. In this case, and depending on its risk-aversion behaviour, the government may adopt different strategies to compute the new entrant supplier reputation. For example, a risk-averse government would considerably limit the number of contracts won by a new supplier. It would also consider a new supplier as having the worst reputation with respect to incumbent suppliers. Instead, a risk-seeking government would consider new suppliers as excellent ones and assign them the best reputation with respect to incumbent suppliers. A risk-neutral government may use different measures to compute new entrants such as the mean, the median or the 75th percentile measures. Finally, one can ask the question if the use of reputation can reduce completion in public sector procurement. Based on suppliers' reputations and depending on the procurement process, a government can eliminate unnecessary interactions and only communicate with trusted suppliers so that their performances may be improved and the procurement completion can be significantly reduced.

As future work, there are several issues that need to be studied. For example, we only considered unilateral auctions in which suppliers bid on contracts requested by a single governmental agency. The case of multi-lateral auctions in which several governmental agencies and suppliers are involved has to be studied. The challenge in this type of auctions is that a combinatorial bid may include contracts requested by different governmental agencies who differently evaluate the suppliers' reputation.

## Appendix A. Formulas

### A.1. Direct reputation

- Time of past arrangement $TA(h)$:

$$TA(h) = e^{-\frac{\Delta t(h)}{\lambda}}$$

where $\Delta t(h)$ is the time difference between the current time and the time $t(h)$ when the arrangement $h$ has been executed by the supplier, and $\lambda$ is a recency scaling factor depending on the time unit used.

- Weigh of arrangement $WA(h)$:

$$WA(h) = 1 - \left( \frac{|Pr(G,h)^2 - Pr^{max}(G,t(h))^2|}{Pr^{max}(G,t(h))^2} \right)$$

where:
- $t(h)$ denotes the time period within which the past arrangement $h$ occurred
- $H(t(h))$ denotes the set of arrangements made by $G$ within period $t(h)$
- $E(G,t(h))$ denotes the performance of the governmental agency $G$ in time period $t(h)$|
- $EH(G,h)$ is the performance of $G$ attributable to arrangement $h$ in period $t(h)$
- $Pr(G,h) = \frac{E(G,h)}{E(G,t(h))}$ represents the percentage of economic saving associated with arrangement $h$
- $Pr^{\max}(G,t(h))$ is the maximum percentage of economic saving over all the arrangements made by $G$ with the participating suppliers within period $t(h)$

- Reliability degree $\xi_d(G,s)$:fc

$$\xi_d(G,s) = \begin{cases} \sin\left(\frac{\pi}{2n_H^*} n_H(G,s)\right) & \text{if } n_H(G,s) \in [0, n_H^*] \\ 1 & \text{Otherwise} \end{cases}$$

where $n_H(G,s)$ is the number of past arrangements made by the governmental agency $G$ with supplier $s$ and $n_H^*$ is the number of arrangements judged acceptable by $G$ to accurately evaluate a supplier.

### A.2. Indirect reputation

- Time of knowledge $\Gamma(WG,s)$:

$$\Gamma(WG,s) = e^{-\frac{\Delta t(WG,s)}{\lambda}}$$

where $\Delta t(WG,s)$ is the time difference between the current time and the time $t(WG,s)$ corresponding to the last update of information given by $WG$ on supplier $s$ reputation. $\lambda$ is the recency scaling factor.

- Importance degree $\theta(WG,s)$:

$$\theta(WG,s) = \frac{N(WG,s)}{NT(WG)}$$

where $N(WG,s_i)$ represents the number of past arrangements made by $WG$ with supplier $s_i$ and $NT(WG)$ is the total number of past arrangements made by $WG$.

- Indirect reliability $\xi_{ind}(G,s)$:

$$\xi_{ind}(G,s) = \begin{cases} \sin(\frac{\pi}{2n_W^*(G,s)} n_W(G,s) & \text{if } n_W(G,s) \in [0, n_W^*(G,s)] \\ 1 & \text{Otherwise} \end{cases}$$

where $n_W(G,s)$ is the total number of witness agencies considered to compute the indirect reputation of supplier $s$ and $n_W^*(G,s)$ is the number of $WG$s judged acceptable by $G$ to accurately evaluate the indirect reputation of a supplier.

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*A.3. Difference in beliefs*

Let $V_c$ denote the value of the criterion $c$ as submitted by supplier $s$ and $B_c$ be the value of $c$ as seen by $G$. In case criterion $c$ is quantitative, $DB(G,c,s_i)$ is computed as:

$$DB(G,c,s_i) = \frac{|V_c^2 - B_c^2|}{Max\left(V_c^2, B_c^2\right)}$$

In case criterion $c$ is qualitative, a step of deffuzification is needed to transform qualitative values into quantitative ones ranging between 0 and 1 (Carbo & Molina-Lopez, 2010). The defuzzification uses the common membership function $\mu(x)\in[0,1]$ which is set by $G$ at the beginning of the procurement process. Hence, the difference in beliefs between $G$ and supplier $s_i$ with regard to a qualitative criterion $c$ is computed as:

$$DB(G,c,s_i) = |\mu(V_c)^2 - \mu(B_c)^2|$$

## Appendix B. Experimental study

*B.1. Mathematical formulation of the WDP*

The WDP is mathematically formulated as a set covering model for which a binary decision variable $x_b$ is defined for each submitted bid $b$. Binary variable $x_b$ equals 1 if bid $b$ wins; and 0, otherwise. The following constraint must be satisfied to ensure that each contract is served:

$$\sum_{s} \sum_{b\in B(s)} \delta_{b,k} x_b \geq 1 \, \forall k\in K. \tag{6}$$

where, $B(s)$ is the set of bids submitted by carrier $s$, $\delta_{b,k}$ is a constant parameter that equals 1 if bid $b$ covers contract $k$ (i.e., $k\in K_b$), and 0, otherwise.

*B.2. Reputation related to an attribute*

The direct and indirect reputations associated with an attribute are computed as follows:

1. Direct reputation of an attribute $\omega_i$: $R_{d,\omega_i}(G,s)$; i = 1,2,3

$$R_{d,\omega_i}(G,s) = \xi_d(G,s)\left(\frac{N'_{Sat,\omega_i}(G,s)+1}{N'_{Sat,\omega_i}(G,s)+N'_{USat,\omega_i}(G,s)+2}\right) \tag{7}$$

where $N'_{Sat,\omega_i}(G,s)$ and $N'_{USat,\omega_i}(G,s)$ are respectively the adjusted number of arrangements where the attribute $\omega_i$ is satisfied (on-time for $\omega_1$, not canceled for $\omega_2$, or not damaged for $\omega_3$) and where the attribute $\omega_i$ is unsatisfied.

2. Indirect reputation of an attribute $\omega_i$: $R_{ind,\omega_i}(G,s)$

$$R_{ind,\omega_i}(G,s) = \xi_{ind}(G,s)\left(\frac{\sum_{WG\in WG(s)} \theta(WG,s)\Gamma(WG,s)R_{d,\omega_i}(WG,s)}{\sum_{WG\in WG(s)} \theta(WG,s)\Gamma(WG,s)}\right) \tag{8}$$

where $R_{d,\omega_i}(WG,s)$ is the reputation associated to the attribute $\omega_i$ of $WG$ with regard to supplier $s$.

*B.3. Hidden costs*

$$HC_d(s,b) = \sum_{k\in K_b} HC_{d(s,k)}$$

$$HC_d(s,k) = \sum_{\omega\in\Omega} C_{k,\omega}(1 - R_d(G,s,\omega))$$

$$HC_{ind}(s,b) = \sum_{k\in K_b} HC_{ind}(s,k)$$

$$HC_{ind}(s,k) = \sum_{\omega\in\Omega} C_{k,\omega}(1 - R_{ind}(G,s,\omega)),$$

where $C_{k,\omega}$ is the unit cost that $G$ would incur with regard to the values taken by the attribute $\omega$ (for example, the cost yielded by a one-day delay). These costs may vary from one transportation contract to another depending, for example, on the type of commodities shipped, its value, the importance of the contract, etc.?, see for more details] journaloftheoperationalresearchsocietyvol12012reputationbased

*B.4. Objective functions*

- Scenario 1:

$$Min \sum_{s\in S} \sum_{b\in B(s)} BP_b x_b \tag{9}$$

- Scenario 2:

$$Min \sum_{s\in S} \sum_{b\in B(s)} BP_b x_b + \sum_{s\in S} \sum_{b\in B(s)} HC_d(s,b)x_b \tag{10}$$

- Scenario 3:

$$Min \sum_{s\in S} \sum_{b\in B(s)} BP_b x_b + \sum_{s\in S} \sum_{b\in B(s)} HC_d(s,b)x_b + \sum_{s\in S} \sum_{b\in B(s)} BP_b.DB(s,b)x_b \tag{11}$$

Observe that the difference in beliefs component is modelled as a percentage increase in the bid price so that bids with large difference in beliefs values are not selected.

- Scenario 4:

$$Min \sum_{s\in S} \sum_{b\in B(s)} BP_b x_b + \beta_1 \sum_{s\in S} \sum_{b\in B(s)} HC_d(s,b)x_b + \beta_2 \sum_{s\in S} \sum_{b\in B(s)} HC_{ind}(s,b)x_b + \beta_3 \sum_{s\in S} \sum_{b\in B(s)} BP_b.DB(s,b)x_b \tag{12}$$

*B.5. Tables of results*

**Table 1**
Direct reputation versus classical selection process.

| Context | Bid price | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| $(\|K\|,\|B\|,\|S\|,\|H\|,\|R\|)$ | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | 3.54 | 2.11 | -15.44 | 10.91 | -0.99 | 2.52 | 37.89 | 16.41 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | 5.45 | 2.30 | -33.43 | 13.73 | -2.66 | 2.66 | 50.73 | 13.63 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | 2.57 | 1.60 | -19.18 | 7.99 | -1.42 | 1.84 | 21.14 | 11.03 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | 3.70 | 2.01 | -34.97 | 13.97 | -1.04 | 2.29 | 32.16 | 14.1 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | 3.08 | 1.97 | -35.02 | 6.42 | -1.48 | 1.64 | 24.57 | 12.06 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | 4.87 | 2.32 | -30.54 | 8.21 | -0.58 | 2.13 | 37.44 | 11.58 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

**Table 2**
Impact of reputation on procurement results.

| Context | Direct cost | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| $(\|K\|,\|B\|,\|S\|,\|H\|,\|R\|)$ | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | 5.32 | 2.55 | -19.06 | 9.81 | -0.40 | 2.45 | 38.20 | 13.87 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | 5.99 | 2.80 | -32.26 | 14.51 | -2.02 | 2.94 | 51.05 | 16.71 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | 7.57 | 3.40 | -41.98 | 9.57 | -4.83 | 2.82 | 19.29 | 12.59 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | 7.42 | 4.78 | -52.06 | 10.29 | -5.67 | 3.01 | 35.87 | 14.09 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | 9.32 | 4.64 | -40.21 | 8.80 | -3.14 | 3.36 | 24.73 | 12.36 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | 9.64 | 4.52 | -58.11 | 11.63 | -5.72 | 2.91 | 36.13 | 11.96 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

**Table 3**
Direct reputation and difference in beliefs versus direct reputation.

| Context | Bid price | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| $(\|K\|,\|B\|,\|C\|,\|H\|,\|R\|)$ | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | -12.64 | 3.57 | -4.59 | 5.43 | -11.06 | 2.88 | 12.14 | 12.29 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | -12.29 | 3.42 | -3.95 | 4.26 | -11.16 | 2.74 | 12.93 | 11.43 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | -3.98 | 5.35 | -5.40 | 4.29 | -4.33 | 3.85 | 12.36 | 9.37 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | -3.53 | 5.18 | -8.33 | 8.02 | -4.30 | 3.58 | 15.54 | 13.67 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | -4.19 | 5.97 | -6.70 | 5.17 | -4.70 | 4.22 | 14.40 | 10.90 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | -2.28 | 4.94 | -8.29 | 5.54 | -3.32 | 3.76 | 19.65 | 10.81 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

**Table 4**
Global reputation versus direct reputation and difference in beliefs.

| Context | Bid price | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| $(\|K\|,\|B\|,\|C\|,\|H\|,\|R\|)$ | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | -1.36 | 1.97 | -8.82 | 5.37 | -2.74 | 1.74 | 15.63 | 13.30 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | -2.30 | 2.35 | -7.97 | 7.67 | -3.02 | 1.96 | 19.07 | 14.33 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | -2.86 | 4.01 | -7.02 | 5.77 | -3.80 | 2.87 | 11.74 | 10.68 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | -4.69 | 3.87 | -4.44 | 5.35 | -4.71 | 3.00 | 19.41 | 12.82 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | -3.64 | 3.42 | -6.66 | 4.75 | -4.31 | 2.75 | 14.58 | 10.98 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | -5.78 | 4.42 | -1.61 | 6.75 | -5.18 | 3.19 | 22.44 | 11.12 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

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**Table 5**
Risk-seeking versus risk-neutral behaviours.

| Context | Bid price | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| (\|K\|,\|B\|,\|C\|,\|H\|,\|R\|) | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | 2.38 | 2.12 | -58.18 | 8.35 | -9.33 | 2.10 | 15.10 | 14.65 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | -1.08 | 2.47 | 25.86 | 22.58 | 2.15 | 3.05 | 23.99 | 14.41 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | 3.11 | 2.36 | -2.71 | 12.78 | 1.75 | 2.78 | 11.46 | 11.51 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | 0.64 | 4.73 | -56.54 | 7.78 | -10.17 | 3.09 | 20.63 | 12.77 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | 1.24 | 2.40 | -1.65 | 14.63 | 0.36 | 2.79 | 13.41 | 9.53 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | -0.28 | 4.61 | 5.30 | 21.26 | -0.09 | 3.36 | 23.65 | 13.33 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

**Table 6**
Risk-averse versus risk-neutral behaviours.

| Context | Bid price | | Hidden cost | | Total | | PCS | |
|---|---|---|---|---|---|---|---|---|
| (\|K\|,\|B\|,\|C\|,\|H\|,\|R\|) | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | 0.54 | 1.64 | -11.07 | 18.30 | -1.60 | 3.50 | 18.42 | 15.08 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | 0.93 | 1.79 | 45.71 | 13.37 | 7.06 | 2.17 | 15.05 | 12.76 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | 0.59 | 2.40 | -9.24 | 13.87 | -1.62 | 3.11 | 10.69 | 9.90 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | 1.42 | 2.57 | 40.29 | 18.88 | 7.83 | 3.39 | 15.33 | 12.06 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | 1.18 | 2.68 | -6.06 | 14.88 | -0.33 | 3.27 | 13.23 | 10.80 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | 2.19 | 3.30 | -12.44 | 16.35 | -0.73 | 3.54 | 17.90 | 11.94 |

AV: average SD: standard deviation.
PCS: percentage of carrier substitution.

**Table 7**
Risk-seeking versus risk-averse behaviours.

| Context | Bid price | | Hidden cost | | Total | | NCCP | | PCS | |
|---|---|---|---|---|---|---|---|---|---|---|
| (\|K\|,\|B\|,\|C\|,\|H\|,\|R\|) | AV | SD | AV | SD | AV | SD | AV | SD | AV | SD |
| (\|20\|,\|100\|,\|10\|,\|1000\|,\|50\|) | 1.86 | 2.57 | -47.62 | 37.00 | -7.70 | 4.70 | 0.00 | 0.00 | 26.61 | 18.84 |
| (\|20\|,\|100\|,\|20\|,\|1000\|,\|50\|) | -1.97 | 2.51 | -12.94 | 17.87 | -4.53 | 3.94 | 0.00 | 0.00 | 34.10 | 14.76 |
| (\|40\|,\|120\|,\|12\|,\|2000\|,\|100\|) | 2.56 | 3.11 | 12.15 | 35.08 | 3.60 | 5.72 | 0.00 | 0.02 | 16.74 | 12.53 |
| (\|40\|,\|120\|,\|24\|,\|2000\|,\|100\|) | -0.75 | 4.17 | -68.51 | 7.00 | -16.63 | 3.71 | 0.00 | 0.01 | 28.97 | 13.35 |
| (\|60\|,\|180\|,\|18\|,\|3000\|,\|150\|) | 0.12 | 3.52 | 10.27 | 39.45 | 0.84 | 5.32 | -0.01 | 0.02 | 21.84 | 11.76 |
| (\|60\|,\|180\|,\|36\|,\|3000\|,\|150\|) | -2.38 | 4.05 | 26.98 | 50.06 | 0.77 | 4.96 | 0.01 | 0.01 | 30.87 | 11.71 |

AV: average SD: standard deviation.
NCCP: non-covered contract percentages; PCS: percentage of carrier substitution.

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