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Public Procurement and Reputation: An Agent-Based Model*

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Abstract

Based on the literature on public procurement regulation, we use an Agent-Based Model to assess the performance of different selection procedures. Specifically, we aim at investigating whether and how the inclusion of reputation of firms in the public procurement selection process affects the final cost of the contract. The model defines two types of actors: i) firms potentially competing to win the contract; ii) a contracting authority, aiming at minimizing procurement costs. These actors respond to environmental conditions affecting the actual costs of carrying on the project and which are unknown to firms and to the contracting authority at the time of bidding. The results from the model are generated through simulations by considering different configurations and varying some parameters of the model, such as the firms' skills, the level of opportunistic rebate, the relative weight of reputation and rebate. The main conclusion is that reputation matters and some policy implications are drawn.

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1 Introduction

The performance of public procurement is a widely debated issue worldwide at political as well as at economic level. The relevant share of public spending involved by public contracts (about 15% of GDP in developed countries) calls for obtaining 'value for money'. Moreover, the potentialities of public procurement as a driver of innovation are widely investigated (Edler and Georghiou, 2007; Hommen and Rolfstam, 2009).

The role of procurement as an instrument to improve overall public sector performance is also increasingly recognized and crucially depends on the set of rules governing public contracts. The 'theory of contracts' emphasizes that rules as well as behavioural codes and institutions, by inserting transactions in more protective governance structures, reduce the potential for conflict and allow mutual benefits for the parties (Williamson, 2002).

Even assuming that public decisions on resource allocation - e.g. what to procure and where – are efficient, still the final outcome mainly depends on the rules for the design of the procedure, the selection of the contractor, the contract award and implementation. According to Williamson (1979) (see also Laffont and Tirole, 1993; Laffont and Martimort, 2001) the economic issues involved in procurement are mainly related to asymmetric information, both in the form of adverse selection (i.e. the problem of choosing the best private contractor) and of moral hazard (i.e. the problem of preventing opportunistic behaviour in the implementation of the contract). Therefore, procurement rules should be designed to address and overcome the above problems Baron and Besanko (1987).

In general terms, the procurement process can be frames as a case of repeated games with asymmetric information (Fudenberg *et al.*, 1994). However, economic theory focuses on abstract results under stringent conditions (such as number and rationality of players, properties of the payoff function, etc.) that cannot be easily adapted to real-world cases. For this reason, the economic problems related to public procurement regulation are widely addressed in the literature adopting a more empirical approach. Several papers investigate awarding procedures, with the aim of identifying the incentives for firms to obtain the best contractual performance (e.g., Bajari and Tadelis, 2006; Ganuza, 2007; Bajari *et al.*, 2009; Bajari and Lewis, 2011; Corts, 2012; Decarolis, 2014)

It is generally believed that the asymmetric information problems related to public procurement can be overcome through procedures designed to ensure competition. Competition is considered as a tool to achieve efficiency and 'value for money' but also to keep contracting authorities accountable by limiting their discretion in selecting the contractor.

Indeed, the efficiency of open procedures should not be taken for granted for public works. In fact, in such a case, unlike supplies contracts, procurement does not refer to standardized products, which already exist in the market, but the execution of the contract implies a production process. Public works in most cases rely on long-term contracts, which are often incomplete (Bajari and Tadelis, 2006). Such incompleteness may give room to opportunistic behaviour of the winning bidder resulting in a pressure to revise the original contract, with a negative impact usually on the time and the costs of realization of public works (Guccio *et al.*, 2009; Bajari *et al.*, 20014).

As a matter of fact, delays and cost overruns in the execution of public works contracts are a widespread phenomenon in most countries (OECD, 2013). Therefore, in the case of public works, the outcome of public action strongly depends on the implementation phase and the rules governing it play a crucial role.

Notwithstanding the importance of the execution stage, most attention is concentrated on the selection stage. At this stage, to overcome the effects of adverse selection, procurement systems usually rely on restrictions to entry, based on qualification schemes for firms. Qualification is claimed to have beneficial effects on the functioning of the competitive system under incomplete information about the firms' capacities (OECD, 2010), provided that the technical, economic and financial requirements which are imposed by the qualification scheme are adequate. Estache and Iimi (2012) stress the relevance of the qualification screening process for the success of any contract; Ancarani *et al.* (2016) investigate the relationship between the execution of public works contracts and firms' qualification in Italy, obtaining robust evidence that fully qualified firms are more efficient in the execution of public works contracts.

Qualification, however, is a static approach, which does not provide incentives to firms in the implementation of the contract. In a dynamic framework a further step could be the selection of suppliers by taking into consideration their past performance on the basis of their track records. Several papers have focused on the role of firms' reputation in order to establish long-term relationships which may have positive effects on public procurement outcomes (see, among others, Doni, 2006; Calzolari and Spagnolo, 2009; Spagnolo, 2012; Coviello *et al.*, 2018).

In particular, Decarolis *et al.* (2016) provide experimental evidence on the strong effect of announcing the use of past performance measures when awarding a public procurement contract; Guccio *et al.* (2012) find that the opportunistic behaviour of the firm is a relevant determinant of performance in presence of competitive tendering and suggest enhancing the role of reputation in the awarding of the contract, to prevent underbidding and the consequent renegotiation of the contract; Spagnolo (2012) presents some novel evidence on the benefits of allowing buyers to use reputational indicators based on past performance and reports preliminary results from a laboratory experiment. Hence, reputational mechanisms can be designed to stimulate rather than hindering new entry; Dellarocas *et al.* (2006) investigate the potentialities of reputation systems through on-line feedback mechanisms to prevent contractual opportunism; Doni (2006) provides a theoretical model to show that including contractors' reputation in the awarding procedures can provide incentives to firms and have positive effects on the quality of the services. Spagnolo and Dini (2005) investigate online 'feedback mechanisms', i.e. reputation systems implemented in most private e-markets and focus on the specific issues emerging when these mechanisms apply to public procurement e-markets.

Using a large Italian database for public works, Coviello *et al.* (2018) show that discretion increases the probability that the same firm wins repeatedly without negatively affecting the procurement outcomes.

In the spirit of this literature, we proxy reputation with the firms' past performance based on their track records and operationalize it as 'revealed contract fulfillment'.[1] Our aim is to focus on how different procedures adopted to select the winning bidder affect the performance of public contracts. Specifically, we are interested in assessing the outcome from public tenders when, other factors being constant, firms' reputation in awarding public contracts is taken into account. To tackle this issue we use an Agent-Based Model (ABM) which, indeed, is not meant to replicate every detail of real-world cases nor to reflect existing regulatory arrangements; rather we aim to contribute to the design of procurement regulations, analyzing how the combination of several different features and of their related effects may interact to generate outcomes. Indeed, the results of simulations offer some insights to evaluate the existing procurement regulations. Specifically, they show that more efficient procurement outcomes can be obtained when it is possible to distinguish virtuous firms (i.e. those charging only legitimate costs) from those adopting opportunistic behaviours (i.e. those bidding a low price to win the contract and, eventually, claiming un-motivated extra-costs) by relying on the firms' reputation. To the best of our knowledge, this type of modeling has not been applied to procurement so far.

The remaining of the paper is organized as follows. In section 2 we briefly introduce the main features of the use of ABM, focusing on the advantages and limitations for policy assessment. Section 3 describes the crucial characteristics of our model. Section 4 presents and discuss the results. Section 5 offer some concluding remarks.

2 Agent-based modeling as policy assessment tool

ABM consists essentially in writing a computer program providing a simplified representation of a real-world setting. Executing the program, the modeler is able to produce a sort of *virtual history* of the simulated system; the study of the simulation may provide insights in understanding specific dynamics in the real world, which is

[1]We are aware that reputation is a wider concept, characterized by different dimensions and issue-specific. Recent surveys for example have addressed the need for a comprehensive and broadly-accepted definition, the difficulty in operationalizing corporate reputation, and the need for further theoretical developments (Walker, 2010; Money *et al.*, 2017).

difficult, if not impossible, to observe.

The methodological use of ABM is still subject to a lively debate. In some cases, ABM is meant to replicate the observed behavior of real world systems (e.g., Dosi *et al.*, 2010). Thus, the main methodological issue concerns the validation of simulation outcomes in respect of available real-world evidence (Fagiolo *et al.*, 2007).

Since the beginning, the use of simulation concerns models populated by heterogeneous bounded rational agents acting out of equilibrium conditions. Academic studies using computer simulations have, therefore, been adopted by scholars concerned with actual events occurring in organizations and markets (Simon, 1996; Cyert and March, 1963; Cohen *et al.*, 1972).

Today, the label ABM is utilized as reference to computer simulation models designed to include interacting agents collectively contributing to non-linear aggregate properties of the system, and are commonly implemented in several areas of social and economic research (Tesfatsion and Judd, 2006).

Simulation models can also be deployed to tackle purely theoretical problems for which real-world evidence is simply not existent. These applications are particularly relevant in the study of potential policies that have never been tested in reality. In these cases simulation models allow for the construction of fictitious systems whose (theoretical) properties can be studied on the basis of arbitrary assumptions applied to the known features of the concerned system (Faber *et al.*, 2010; Di Maio and Valente, 2013). Further, empirical validation is obviously impossible and therefore a different methodological protocol to assess the results is required.

Our paper contributes to the recent literature exploiting ABM's to assess the effects of hypothetical policy initiatives (e.g. Dosi *et al.*, 2017). Following the methodological approach developed in Valente (2017), rather than calibrating the model on real-world data and validating the model by comparison with existing observations, we produce a virtual representation of the entities relevant in a generic procurement system. The analysis consists in assessing the properties of the model and the mechanisms producing those properties under several hypothetical conditions, which can provide relevant indications for real world systems, in our case insights to evaluate innovative procurement regulation.

3 Model description

Formally, we define "a model" as a set of variables associated to "equations", implemented as chunks of computer code producing a numerical value at each time of their execution. The value for each variable will be affected by the values of other variables included in its equation, besides, possibly, constant parameters. A simulation run consists in the repeated computation of all the variables of the model in a sequence of time steps, where some of the variables' values from a time step are fed into the computation of the values of variables in the following time step.

The model generates as a result time series of values for each variable; its statistical elaboration allows to interpret both the results and, most importantly, the logical connections linking the model configuration (functional form of the equations and initial values) to the results. The interpretation of these logical links allows to produce solid conclusions on the properties of the simulated system, whose translation to real world cases, though cannot be taken for granted, may provide useful insights.

Our ABM aims at investigating whether and how the inclusion of firms' reputation, as crucial feature in the public procurement selection process, may affect the final cost of the contract. The proposed model defines two types of actors: i) firms potentially competing to win the contract; ii) contracting authority, aiming at obtaining 'value for money'. These actors respond to environmental conditions determining the actual costs of carrying on the project and unknown to firms at the time of bidding and to the contracting authority. We are able to control any aspect of the model, so as to assess how firms' features, selection criteria adopted by the contracting authority, and environmental conditions concur to determine the outcome of the virtual contracts.

A simulation run consists in a sequence of steps, each of which represents a virtual round for a public contract. Our model assumes a large number of contracts offered to the same set of firms, so that, at the end of the simulation, we can collect the final values generated within each setting and assess the influence of specific conditions. During a single step of a simulation run all firms submit a bid to win a contract. One of them is assigned the contract; the related work is executed at the cost specified in the bid increased, possibly, by unexpected cost overruns. In line with the above mentioned literature, in our model the costs overruns can be due to: i) unforeseen technical difficulties encountered by the contractor during the execution of the contract; ii) extra-costs charged by the contractor and opportunistically omitted from the bidding price in order to win the contract. The contracting authority is assumed to be not able to distinguish between the two motivations, but clearly wishes to punish opportunistic firms while clearing firms claiming legitimate extra-costs.

Our results show that the awarding authority can select the best firms (i.e. those charging the lower final bill) by relying on the reputation of bidding firms. We use as a proxy for reputation an index based on the data of cost overruns claimed by winning firms at the end of their contract on top of the price stipulated on their bid, whatever motivations for these extra costs. The model assumes that firms may advance overrun cost for reasons legitimate (truly unexpected events) or opportunistic (strategically planned at the time of bidding). The index, leveraging on the statistical differences between the two cases, allows the awarding authority to automatically identify the nature of the firms and favors the firms with the best features from both a technical perspective, i.e. having the lowest production costs, and a strategic perspective, i.e. with the lowest probability of charging unjustified extra costs.

The model includes several random events, simulating the variability of conditions faced by real-world cases. We can control the probability distributions of these random events, so that while cumulating the results over several time steps (representing several contracts), we can assess the average performance of the selecting criteria adopted by the contracting authority.

In the following paragraphs we provide the details of the model. As already mentioned the focus of this work concerns the capacity of a public agency in selecting the most effective firms among those bidding for a public contract. Consequently, we are not interested in the events taking place within firms, e.g., their profitability, competence development, internal organization, etc. Such aspects are obviously relevant in case one would discuss the industrial dynamics of a set of firms, but, in our case, the only aspects of firms relevant for an awarding authority are: 1) the skills of the firm in fulfilling work entailed by the contract; and 2) the possibility for the firm to resort to opportunistic strategies, i.e. bidding a lower price to win the contract with the intention to claim a higher payment pretending made-up extra-cost. Both elements contribute to determine the bidding price requested by firms, and the difficulty for the awarding authority is that it is generally difficult (and we assume impossible) to distinguish the contribution of the two components in forming the submitted bid in a public tender.

Below we describe the variables comprising the model and their functional representation. We begin by presenting the internal estimation of cost by firms, which is the base for the computation of the discount on the reserve price that the firm is expecting to find profitable on the basis of its capacities. The actual bid submitted in the tender is computed summing up the estimated discount and an additional, opportunistic discount that the firm applies so as to increase the chances of winning the contract, even though it plans recoup these costs at the end of the contract by fraudulently claim non existing extra-costs. Finally, we describe the reputation index assigned to the firms by the awarding authority and the selection mechanism adopted to choose the firm winning the contract.

3.1 Firms' bidding price

Each firm at each time t computes its bidding price as the final result of a process that takes into account the specific capacity of the firm, a random component, and the strategic discount the firm plans to recoup by falsely claim fictitious unplanned costs. For simplicity, we assume that all firms provide the same quality of service, and the only difference is the price charged, expressed as discount on the reserve price.

The first step in defining the firm bidding price consists in estimating the real cost that the firm expects to face in case it is awarded the contract. This cost is computed by the firm on the basis of the self-evaluation of its skills in performing the required works, and a random component capturing possible estimating errors.

Formally:

$$C_i^{Est} = C \times (1 - S_i) \tag{1}$$

where C represents the reserve price published by the contracting authority (and hence identical to all firms), the maximum cost to perform the work, implicitly including a share of profits. S_i represents the "skill" of the firm expressed as a percentage, with values ranging from 0, for firms unable to reduce the cost below the reserve price, to 1, for firms capable to deliver the contract at no costs. Equation (1) shows that firms with the higher skills S_i will generate the lower estimated costs.

Notice that within the levels of "skills" used to estimate the cost, we implicitly include also the desired level of profits the firm aims to gain from the contract. In fact, from the perspective of the contracting authority, there is no difference between a highly skilled firm, able to perform the desired work at low cost but chasing very high profit margins, and a less capable firm satisfied with lower profits.

Once the firm has estimated the expected cost, it computes the rebate on the reserve price it could offer on the basis of its own estimation of the production costs:

$$R_i^{Est} = 1 - \frac{C_i^{Est}}{C} \tag{2}$$

The estimated rebate R_i^{Est} is a percentage ranging from 0 when the firm expects to have costs identical to the reserve price, $C_i^{Est} = C$ to 1 when the firms estimates no costs $C_i^{Est} = 0$.

The rebate estimated on the basis of the technical conditions may be increased by an additional reduction that the firm plans to declare opportunistically in the official bid. This is done in order to increase the chances of winning the contract, but represents costs that the firm plans to recoup at the end of the contract by falsely claiming un-expected production difficulties to justify a payment above the agreed price indicated in the bid. Formally:

$$R_i = R_i^{Est} + R_i^{Opp} \tag{3}$$

The higher the parameter R_i^{Opp} the higher the final bid for the firm, and hence, as we will see below, the more likely will be winning the contract. This parameter represents therefore the propensity of a firm to game the system relying on the impossibility of the contracting authority to distinguish between justified claims of the costs overrun, due to genuinely unexpected difficulties, and the opportunistic ones, planned at bidding time.

Our model is designed to assess the results depending on different degrees of opportunism among competing firms, while it is not able to discuss the existence and the origins of such a behavior. For this purpose, we also assume that a firm adopts a fixed and constant level of opportunistic rebate. This assumption clearly simplifies the interpretation of the results, while in real world the tendency of firms to resort to such behavior may change through time. Nevertheless, as noted above, we aim at investigating the mechanisms linking certain conditions to specific results, and to this end what matters is the relative distribution of firms adopting opportunistic behaviors (that we control). The possible dynamics of opportunistic tendencies are outside the scope of the present work.

The bidding price, submitted in the tender for the contract, is computed discounting the rebate from the reserve price:

$$B_i = C \times (1 - R_i) \tag{4}$$

3.2 Final cost and Reputation

The bidding price is the relevant parameter for the contracting authority to select the firm winning the contract. At the end of the contract the authority evaluates the performance of the winning firm, one for each round of a simulation run, by considering the actual cost charged by the firm. The final cost differs from the bidding price because of unpredictable extra-costs encountered during the execution of the contract and that the firm is entitled to charge.

$$C_i^{Final}[t] = B_i \times (1 + EC_i[t]) \tag{5}$$

The equation above shows the crucial elements at the core of our analysis. The firm winning the contract aims at maximising the revenues obtained by the contract, i.e. C^{Final}, but, in order to win the contract in the first place, the firm needs to minimize the bidding price B_i. Hence the extra costs $EC_i[t]$ represents the core element of the model.

We assume that the awarding authority does not have the capacity to assess whether the claimed extra-costs are due to legitimate overruns related to errors in the estimation of the reserve price or, on the contrary, they depend on the strategic under-bid by the company that, since the beginning, planned to overcharge above the bidding price. Formally, we assume that the extra costs are composed by the sum of the opportunistic rebate and legitimate cost overruns encountered during the execution of the contract:

$$EC_i[t] = R_i^{Opp} + OR_1[t] \tag{6}$$

The unexpected overruns are produced as a random variable generated from a normal distribution with mean 0 and variance σ.

While in real-world cases there is generally the possibility for the contracting authority to verify, at least partially, the plausibility of extra costs at the end of a contract (and, potentially, challenging them), we assume for simplicity the extreme condition, i.e. that the contracting authority is not able to distinguish planned opportunistic extra-costs from legitimate ones, generated by actual complications emerged during the execution of the contract. Consequently, the only information available to infer the reliability of a firm is to compare the final cost applied by the contractor with the relevant bid price, regardless of the possible causes of divergence. We aim at investigating whether in such conditions there may be a strategy for the contracting authority to reduce the damage due to the opportunistic behaviors.

We assume that the contracting authority maintains a register in which it records the performance through time of the firms to which it assigns contracts. Within the register each firm is associated to an index of reliability, called *reputation*, which is updated any time the firm completes a contract. For the purpose of this work we ignore likely complications in the management of this register due, for example, to the entry of new firms lacking a history of contracts won in the past. As a preliminary study we want to focus on whether such register could be effective in taming opportunistic tendencies by firms, exploiting the format of the agent-based model to reconstruct the mechanisms by which taking into account reputation reduces the costs of public procurement. In case of an operational application of reputation in assigning contract we believe that it should be relatively easy to create an electronic register shared by all contracting authorities maintaining the values of such indexes for all concerned firms. In the final discussion we expand on the empirical implications of our findings.

In order to operationalize the concept of reputation developed in the literature on repeated games, we consider an index for each firm cumulating the evidence available to the awarding authority concerning the behaviours of the winning firms through multiple rounds of distinct tenders, each assumed for simplicity to be identical.[2]

Formally, at each time step t the reputation index of the winning firm is modified according to the following equation:

$$T_i[t] = T_i[t-1] \times \gamma + (1-\gamma) \times \frac{B_i}{C_i^{Final}} \tag{7}$$

Equation (7) deserves some comments. Only for firms winning and executing the contract the reputation index changes, depending on the ratio of their bidding price and the final costs (for other firms reputation remains unchanged). Given the assumptions described above, the final cost can be equal or larger than the bidding price, so that the ratio of the second component of the equation takes a maximum value of 1. In general, the ratio is lower the larger the final cost with respect to the bidding price. The functional form describes a sort of weighted average between the old value of reputation and the current result, with γ representing the relative importance of the past with respect to the most recent information. When $\gamma = 0$ the reputation of a firm corresponds always to the ratio bid/final cost recorded the last time the firm won a contract. On the other extreme, when $\gamma = 1$, the reputation

[2]Varying the level of the contract value and/or reserve price would not alter in any way our results.

of a firm does never change, remaining constantly equal to its initially assigned value. For the general case of intermediate values for γ we can represent a smoothed dynamics where any contract won by a firm shifts the reputation at an intermediate level in between the past level and the newly recorded performance. The property of such a system is that in the long term, when the number of contracts won is sufficiently large, the reputation index approaches the expected ratio of the bid over the final cost. This value will be smaller, other things being equal, for the firms having a higher opportunistic behaviour.

3.3 Selection procedure

The final equation of the model concerns the mechanism by which the contracting authority assigns the contract among the competing firms. The mechanism consists in evaluating all the firms bidding for the contract and choosing the one to award the contract. While in our model we consider exclusively the firms' bidding price and their reputation index, we adopt a modeling format implicitly representing the case where firms are assessed along a wider range of characteristics, potentially affecting both features of the firms or aspects of the proposed contract. For this reason we analyze a selection mechanism of the winner which includes a random factor, though the chances of winning are higher for firms enjoying the highest rebate and the best reputation. Formally, the firms are selected randomly according to probabilities proportional to the following index, computed for each firm at each time step:

$$I_i[t] = \left(T_i[t-1]^a \times R_i^{(1-a)} \right)^b \tag{8}$$

The indices for all the firms are turned into probability by standard normalization:

$$Prob(i = winner) = \frac{I_i[t]}{\sum_j I_j[t]} \tag{9}$$

Summing up, at any time step each firm computes its rebate, then the awarding authority uses this information and the reputation index to define the probability associated to each firm; then draws randomly one firm according to those probabilities.

The format of equation (8), and consequently of the probabilities of winning the contract, allows to explore a variety of possible conditions. Parameter a expresses the relative importance of the reputation with respect to the rebate value, as a criterion to choose the winner and to award the contract. For example, setting $a = 0$ we represent the contracting authority dismissing the reputation and considering only the rebate as motivation to choose the winning firm. Viceversa when $a = 1$ only the reputation index plays a role. In general, for intermediate values of a we produce settings where the relative importance of the two types of information are more or less relevant in assessing the tender's winner.

Parameter b represents the intensity of competition, meaning that we can tune the model to provide more concentrated or distributed probabilities. To appreciate the effect produced by different values of b, we consider a set of firms with varying levels of reputation and different rebates and a given level for a, and compute two sets of indices $I_i[t]$ using two different values for b. In both cases the relative ranking position of each firm will be identical in the two sets. However, the probabilities of the top ranking firms, those with the highest indexes, will be much higher when using a higher value of b with respect to the probabilities computed with the lower value. This case can be interpreted as a market characterized by stronger competition, effectively restricting the actual chances of being selected to only a few, top performing firms. On the contrary, with a low level of b, the probabilities are more evenly spread across all firms, though the best firms still enjoy a comparatively higher chance of being selected. This second case represents a market with weak competitive pressure, since over repeated draws a larger number of firms will be selected.

4 Model properties

Though relatively simple in its functional structure, the properties of the model depend on the non-linear interaction among several agents, requiring therefore the use of numerical simulations in order to assess its properties.

The results from the model[3] have been produced by considering different configurations and varying some parameters, such as the firms' skills, the level of opportunistic rebate, the relative weight of reputation and rebate, etc. Comparing these results we will be able to highlight logical properties of the proposed model and shed light on the outcome that may be expected from different regulation alternatives and environmental conditions. It may be worth repeating that the simulations presented are not aimed at being realistic; indeed, the goal is to identify the mechanisms acting within the simulated virtual system, so as to derive useful insights to interpret real world evidence as well as policy implications.

The ultimate goal of the model is to support the claim that even the use of an approximate index of reputation based on observed past results is able to strongly improve the capacity of the awarding authority to select the most cost-effective firms. The application of ABM methodology permits not only to assess the overall robustness of our claim, which is clearly limited by the abstract nature of the model, but also to reconstruct the logical steps of *how* reputation leads to this result. The capacity to extract the single components of the logical mechanism at work is the most relevant contribution, since they can be expected to apply both in the

[3]The model is implemented with the *Laboratory for Simulation Development - LSD* (Valente, 2008). Source code and configurations are available upon request.

theoretical model as well as in real-world cases. For this reason we present the results from simulations with increasing levels of complexity, in order to highlight the contributions of individual elements of the model to the overall results.

We present four scenarios. Scenarios 1a, 1b and 1c provide preliminary evidence, based on extremely simplified configurations, mostly aimed at clarifying the single effects of the model's core dynamics; scenarios from 2 to 4 provide more complex results including the interplay of the different components of the model.

In all the scenarios presented below, we consider a simulation run made of a large number of steps (5,000); during each of them a contract is awarded to one among 1,000 firms. These large values, obviously exceeding any reasonably realistic case, are due to the necessity to smooth away the effects of randomness and to increase the reliability of results.

4.1 Scenario 1a: Introduction

We first consider the outcome produced when the reputation is completely ignored. To this end we test the effects generated when the contracting authority evaluates firms only on the basis of their bid, rewarding with a higher probability of winning the contract the firms which present the highest rebate. We also assume that firms do not apply any opportunistic rebate and the probability of unexpected problems is set to null, so that the final cost depends only on the skills of the firm (i.e., its actual cost, including the implicit profit).

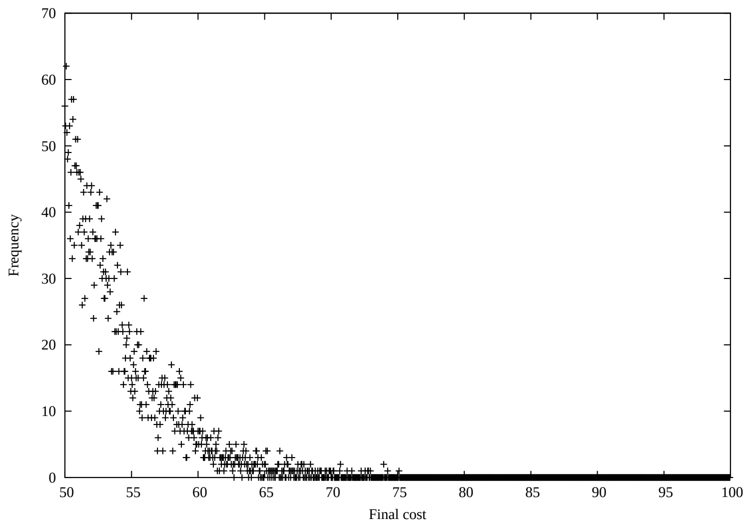

Figure 1: Frequency of contracts awarded distributed according to their final cost.

Figure 1 shows the data obtained at the end of a simulation run. It reports on the horizontal axis the final cost charged by the winning firm at each time step and, on the vertical axis, the frequency with which that level of cost occurred. The configuration includes firms with different levels of skills, and, therefore, final cost. The result shows clearly that firms with the highest cost (lowest skills) are never selected (the reported frequency is equal to zero), suggesting that they never manage to win a contract during the whole simulation run. Firms with mid- to low-cost (mid- to high skills) correspond to increasing frequencies; maximum frequencies are reached for those with the lowest cost. The distribution is noisy due to the random component in the selection mechanism. As noted above, this mechanism generates higher probabilities that the contract is awarded to firms with the highest rebate bids, but any firm enjoys at least an infinitesimal, non-zero probability of being chosen.

4.2 Scenario 1b: Reputation and skills

Figure 2 reports the values of the reputation index earned by the firms ranked according to their skills. This index is updated only for the firms which have been awarded a contract at each time step. Therefore, the more contracts a firm wins the more frequently its index is updated. Under the conditions adopted for this scenario, the index can only grow from its initial low level of 0.5 because firms never indulge in opportunistic behavior and there is no randomness in the costs. Consequently, a) the reputation index can only increase, approaching the long-term maximum level of 1, and b) at any given time, we observe that the firms with larger number of awarded contracts also show the best reputation indexes.

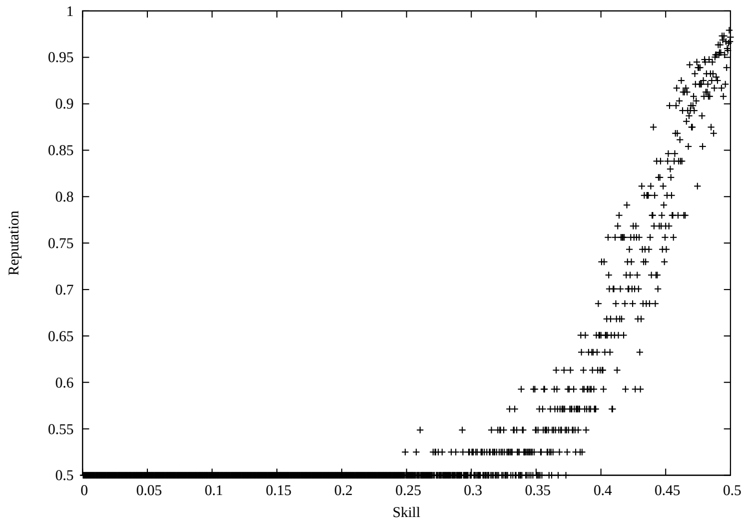

Figure 2: Reputation index for firms distributed according to their skills.

4.3 Scenario 1c: Selection mechanism and competitiveness

As last evidence, we consider the effect of the selection parameter. The strength of competitiveness is controlled by the parameter b, whose higher values favour the selection of firms with the highest indicators. In this simplified configuration, meant to introduce the elementary dynamics of the model, firms refrain from opportunistic bidding, and consequently the indicators coincide with the skill of the firms. Therefore, the highest the indicator, the lowest the final cost charged by the firm if it was awarded the contract. Selecting firms with the best indicators thus favors the selection with the highest skills, and guarantees lower costs.

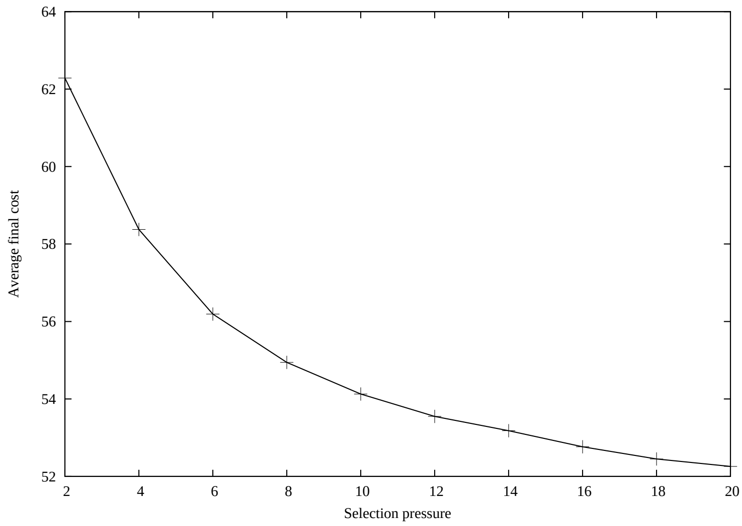

Figure 3: Average final cost of awarded contracts and selection pressure. Comparison of the average final cost over all contracts awarded during a simulation run using 10 distinct simulations based on different levels of selection pressure (parameter b).

Figure 3 reports the data from ten distinct simulations each using the same set of firms and ten different values for the selection pressure. The graph reports on the horizontal axis the value of the parameter controlling the selection pressure and on the vertical axis the average cost paid by the awarding authority. Configurations with lower selection pressure spread their choice more widely, giving higher chances of being selected to firms with less than optimal skills. On the contrary, increasing the selection pressure, the range of firms selected is narrowly restricted to those with the highest skills, resulting in lower costs.

4.4 Scenario 2: Effects of opportunism

The effectiveness of the selection pressure in identifying the best firms and allowing the contracting authority to minimize the final cost is heavily reduced, and potentially disappears, when the firms leverage on the impossibility to distinguish genuinely unexpected extra-costs or opportunistic behaviours.

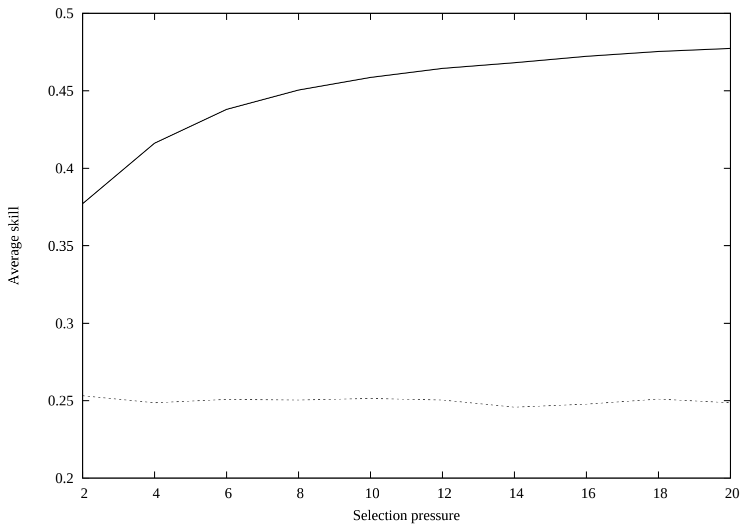

Figure 4: Average skill of the winning firms for different levels of selection pressure. Thick line represents data from experiment 1, where firms do not use opportunistic rebates. Dashed line refers to experiment 2, where firms apply a level of opportunistic rebate inversely proportional to their skills.

To support this result we consider the simulation used in the previous exercise and modify the parameters, defining the level of the opportunistic rebate, previously set to 0 for all firms. In this second scenario firms adopt different levels of opportunistic rebate, inversely proportional to their skills. In other terms, firms with low skills compete with a low bid price but, in case of winning the contract, they will charge a higher price, pretending opportunistic extra-costs, so that the work becomes more expensive than expected.

Figure 4 shows the average skill level of the winning firm on the vertical axis for different levels of the selection pressure. The continuous line reports the results from scenario 1, where firms do not engage in opportunistic activities, while the dashed line considers the results from this second scenario with opportunistic firms. It is evident that the selectivity of the contracting authority has no effect in the second case, since the skills of the winning firms remain constantly low independently from the concentration of probabilities. The reason for this result is that all firms submit low bids, and the contracting authority is not able to distinguish those doing so because of their high skills from those planning to claim opportunistic extra-costs.

4.5 Scenario 3: Reputation vs opportunism

In this third scenario we show how considering the reputation gained by a firm helps in contrasting opportunism. As in the previous exercise, we analyze a set of firms whose opportunistic rebate is inversely proportional to their skills. We consider two distinct simulation runs for the same set of firms. In the first run, the contracting authority takes into account only the level of the rebate to select the winner of the tender (value of $a = 0$), while in the second it also cares about the role of reputation ($a > 0$).

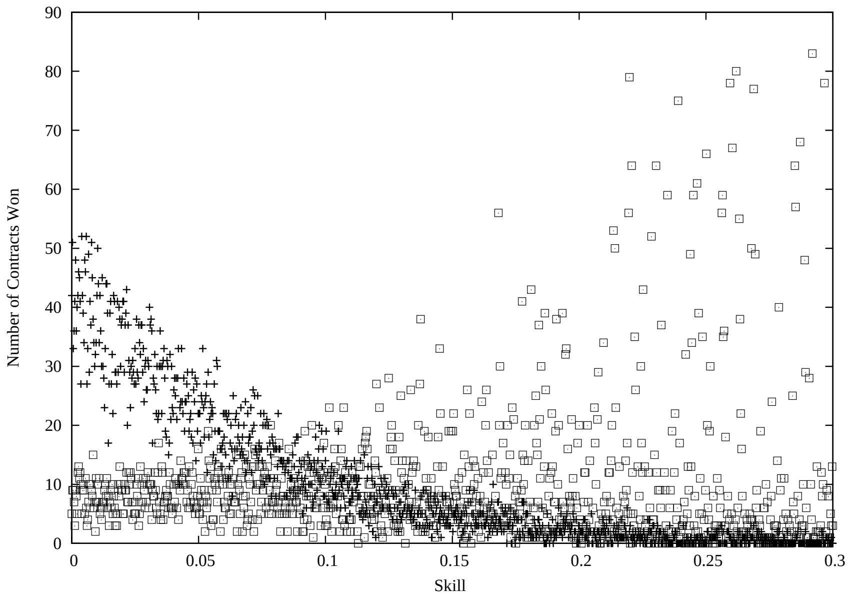

Figure 5: Number of contracts awarded to firms with opportunistic rebates inversely proportional to skills. The graph reports the data from two simulations run on the same set of firms. The cross symbols refer to the configuration ignoring the level of reputation, while the squared symbols refer to the simulation using reputation as criterion to assign contracts.

Figure 5 displays the records for the individual firms at the end of the simulation run. On the horizontal axis the graph reports the level of the skill of the firm, while on the vertical axis it shows the number of contract won. The cross symbols refer to the configuration where the contracting authority ignores the reputation of the firms. In this case the firms with the largest levels of opportunistic rebate have larger chances of being selected. Since the opportunistic rebate is negatively correlated with the skills, this setting effectively rewards worse firms with higher number of contracts. The squared symbols refer to the configuration where the contracting authority also considers the level of reputation that increases more markedly for the firms with the lowest levels of opportunistic rebate. This configuration rewards the firms with the higher skills, since those with the higher opportunistic rebate see their reputation falling comparatively to those with higher skills.

4.6 Scenario 4: Reputation and randomness

In this final scenario we analyze the results produced when the final cost is affected both by skills and opportunism and also by genuine extra-costs due to unexpected problems occurred during the execution of the contract. Consequently, the contractual cost and the final cost may differ because of two possible reasons: opportunism or unforeseen contingencies. Having assumed the extreme scenario in which the contracting authority has no chance to distinguish the two cases, it may be reasonable to expect that the reputation, computed in terms of cost overruns, fails to identify firms with higher opportunistic tendencies. As before, for benchmarking we also report the same data from a configuration without the use of reputation.

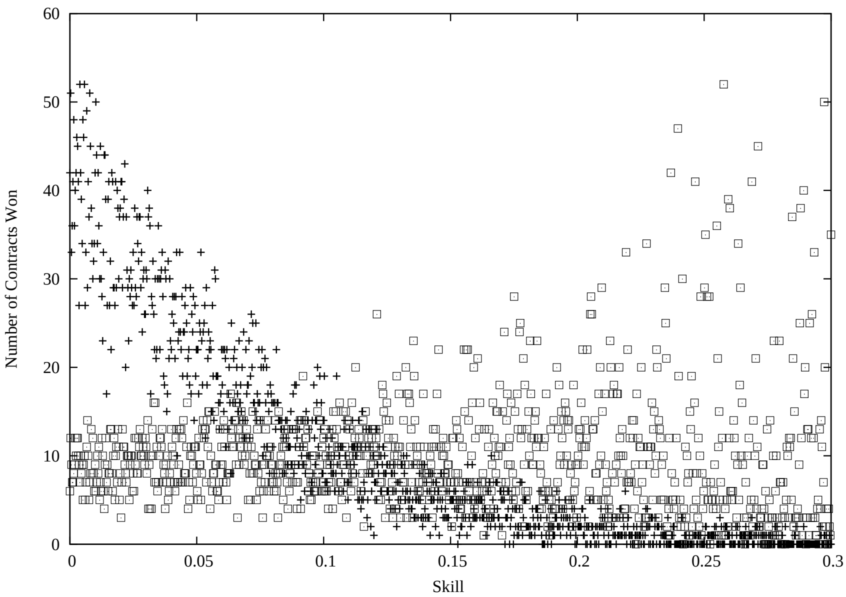

Figure 6: Number of contracts won for firms with opportunistic rebates inversely proportional to skills, in presence of randomness. Same data as in figure 5 but the simulations include also a random component affecting the final cost, so that a difference between contractual cost and final cost may depend from opportunism or genuinely un-expected extra costs.

Figure 6 shows that the reputation continues to correctly discriminate against firms claiming unjustifiable higher costs. The graph reports the same data shown in figure 5, that is the number of contracts won by firms ranked according to their skills. Reminding that in this setting the level of opportunistic behavior is inversely proportional to the skills, the graph can be interpreted as showing the firms inversely ranked according to their opportunism level. The results are fundamentally identical to those generated without the possibility of extra-costs, proving that the presence of randomness does not modify the effectiveness of the reputation index. The only minor difference is the wider distribution of contracts among the highly skilled firms, suggesting a weakening impact of the reputational effect in promoting less opportunistic firms. However, these results maintain the rather extreme assumption that the awarding authority is unable to distinguish between legitimate cost overruns, due to unforeseen technical difficulties, from opportunistic extra-costs planned at the time of bidding. If the contracting authority had the possibility to investigate claims of extra-costs so as to expose even a small percentage of the opportunistic behavior, the effectiveness of the reputational effect would be strengthened.

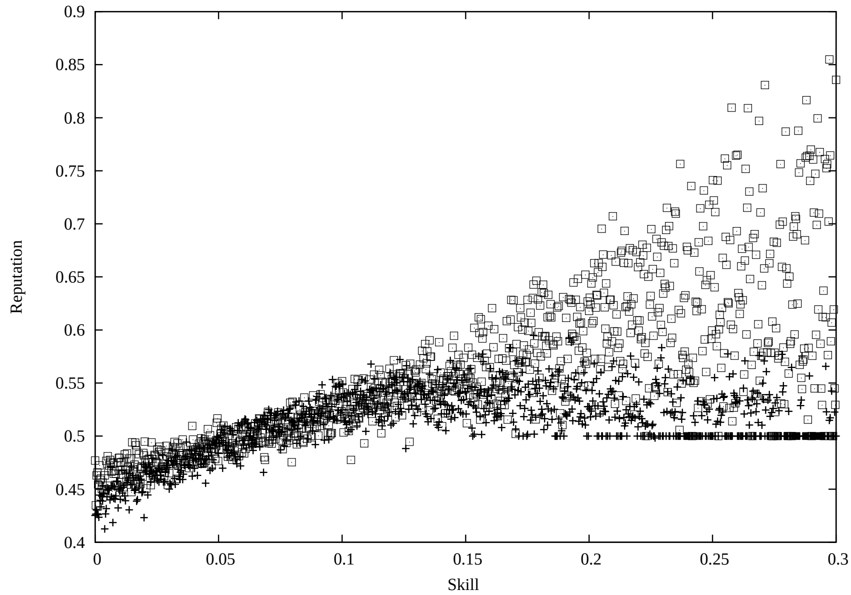

Figure 7: Effectiveness of reputation index. Same simulation as in figure 6. The graph reports the reputation levels of firms in respect of the skills. Square symbols refer to the configuration considering the reputation level to assign the probabilities of firms to be awarded the contract ($a > 0$), while the crosses report data from the simulation ignoring reputation ($a = 0$).

The reason for the substantial robustness of the reputation in identifying the firms with the least opportunistic level (and higher skill) relies on the merely statistical effect of the randomness of difficulties. Both honest and opportunistic firms have the same chance of facing unexpected difficulties and, consequently, of reporting a different final cost at completion. However, opportunistic firms will present a wider difference on average. This difference, cumulated over several contracts, cause the reputation index to diverge, confirming its effectiveness. To support this claim we report in figure 7 the level of the reputation index for the same firms as in figure 6. It is worth noting that the simulation, where the contracting authority adopts the reputation as criterion to assign the contract, enhances sensibly the reputation of the least opportunistic firms in comparison to the case where the reputation is ignored. Obviously the reputation cannot reach the maximum level of 1 since, even if they are perfectly honest, firms still face un-expected extra-costs. However, opportunistic firms have lower scores and, therefore, can be easily identified.

5 Concluding remarks

In this paper we used ABM as a tool to offer some insights on public works procurement regulation. The main results stemming from our analysis confirm the conclusions reached in the theoretical and empirical literature about the relevance of reputation as a means to disincentivate opportunism in competitive procurement, to favour the assignment of a contract to the most skilled firm and to reduce the risk of cost overruns. Some operational issues and policy implications deserve attention in the case of public works procurement. The design and the implementation of appropriate reputation mechanisms in public contexts interact with - and are affected by - the propensity toward innovation existing within the public administration. Taking into account firms' reputation on a systematic basis would imply to introduce innovation and increase the degree of digitalization in the procurement procedures. On the one hand, including reputation would be a "cultural" innovation because it would expand the set of information to be considered by the contracting authority. On the other hand, implementing a reputation mechanism that links performance to future contract awards requires procedural innovations in the production and distribution of the relevant information flows, and in the related technological solutions. Contracting authorities need to be part of a network sharing online information on each contract performance and the operation of such a system depends on the institutional setting. At the same time, the extent of digitalization within the public administration crucially affects the capability of implementing such a structured network.

By suggesting to include reputation as a selection criterion when deciding the assignment of a contract, our analysis contributes to the current debate on public procurement in the European Union, which is evolving in this direction. This issue is particularly relevant in Italy where the latest version of the Legislative Decree n.50/2016 (Procurement Code – *Codice dei contratti pubblici*) as modified by the law n. 96/2017 has introduced a reputational mechanism, i.e. a 'firms rating' mechanism, based on the potential contractor's past performances and aimed to be used both as a selection criterion of the contractors and a contract award criterion. However, the general principles provided by the law seem to be a weak answer to a crucial issue affecting the performance of public contracts. Indeed the mechanism is voluntary, rather than being a compulsory requirement to be evaluated by contracting authorities and this may effectively weakens the role of reputation in awarding the contract. The specific guidelines to regulate this new tool and to operate it by the National Anti Corruption Authority (ANAC) are still underway and no evaluation is possible at the moment.

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Appendix

The model is implemented using *Laboratory for Simulation Development - LSD*, a simulation platform specifically designed to implement and analyse agent based models. The model code and configurations used to generate the results are available to readers on request. The open source platform can be obtained at `www.labsimdev.org`, including both source code and user documentation.

The following table reports the elements presented in the paper and the corresponding labels used in the code. Where appropriate we indicate the values used in the simulation runs. All the specific values as well as the functions implementing the model are indicated in the configuration files accessible to users.

Central Elements			
Model label[4]	**Text label**[5]	**Value**[6]	**Description**
`Select`	–	(variable)	Choose the winning firm and updates a model statistics
`Cost`	C	100	Reserve price published by the awarding authority
`bTrust`	γ	0.95	Speed of adjustment of the reputation index.
`aTrust`	a	(varying)	Relative weight of trust as opposed to cost in the selection procedure .
`Risk`	σ	(varying)	Variance of the normally distributed random values of overruns
`SelPressure`	b	(varying)	Index of competitiveness
`SSkill`	–	–	Statistic representing the firms' average skills weighted by the shares of contracts won.
`avFinalBill`	–	–	Statistic representing the average final cost charged by all applicants weighted by the shares of contracts won.
Firms' Elements			
`idFirm`	i	(varying)	Identification code
`Skill`	S_i	(varying)	Skill of the firm, the higher this value the lower the bid, other things being equal.

`EstimatedRebate`	R_i^{Est}	–	Estimated rebate, prior of possible strategic discount for opportunistic rebate
`EstimatedCost`	C_i^{Est}	–	Estimated cost of completing the contract.
`Rebate`	R_i	–	Submitted bid, including cost estimation and opportunistic rebate.
`OpportunisticRebate`	R_i^{Opp}	(varying)	Level of strategically charged rebate that the firm plans to recoup by claiming non-existing overruns.
`Trust`	$T_i[t]$	0.5 (initial)	Reputation index updated for firms winning the contract as a function of final cost and bid cost.
`Win`	–	0 (initial)	Number of contracts won.
`FinalBill`	C_i^{Final}	–	Final cost charged in case the firm had won the contract, including legitimate costs and opportunistically planned overruns.

[4]Label appearing in the model code and configuration.

[5]Label appearing the text.

[6]Values for parameters if constant. When indicated the values used change with the configurations presented.

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