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Public procurement and reputation. An agent-based model

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[Correction added on 14 September 2023, after first online publication: First name of the author 'Romilda Rizzo' has been corrected to 'Ilde Rizzo' in this version.]

Abstract

This paper uses an agent-based computational model to investigate whether and how considering the firm's reputation in the public procurement selection process affects the expected final contract cost. We take account of different sets of simulations and a range of model parameters (such as firm skills, level of opportunistic rebate, relative weights of reputation and rebate) and propose a reputation index based on the cost overruns recorded by winning firms at the conclusion of their contracts. We show that this index allows the awarding authority to (i) select the most efficient and the least opportunistic firms, and (ii) to exclude firms that engage in frequent opportunistic behavior whose reputation has declined. Our results suggest that reputation matters, and we derive some implications for policy.

KEYWORDS

agent-based modeling, procurement, public works, reputation

JEL CLASSIFICATION

H57, L14, C63

1 | INTRODUCTION

The performance of public procurement is a highly debated issue worldwide at both the political and economic levels. The share of public spending allocated to public contracts which is around 15% of GDP in developed countries (OECD, 2021) calls for the need to ensure value for money. The use of procurement as a tool to improve overall public sector performance has been acknowledged, and

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depends crucially on the rules governing public contracts related to the design of the procedure, the selection of contractors, and the execution of the contract (Bajari et al., 2009).

There is a substantial body of work which sees competition as a means to ensure efficiency and value for the taxpayer's money while making the contracting authorities accountable by limiting their contractor selection discretion (Baltrunaite et al., 2021; Coviello et al., 2018).[1] However, the efficiency of open procedures should not be taken for granted for public works (Guccio et al., 2012; Rizzo, 2013). Whereas supplies contracts refer to already existing standardized products, procurement of public works implies a production process, and in most cases involves long-term and often incomplete contracts (Tadelis & Bajari, 2006). Incomplete contracts provide room for opportunistic behavior from winning bidders and pressure for revisions to the original contract which are likely to have a negative impact on the time and/or the costs of realization of the public works (Bajari et al., 2014). Delays and cost overruns related to the execution of public work contracts are a widespread phenomenon in most countries (Cavalieri et al., 2019; OECD, 2013).

Whatever the procedure chosen–open or restricted[2]–the administration awarding the contract can employ the criterion of either "lowest price" or "most economically advantageous tender".[3] Over time, EU directives have emphasized criteria other than simply price in the evaluation of tenders with member states while maintaining degrees of freedom on the application of the "lowest price" criterion.

To overcome the potential effects of adverse selection in the choice of supplier, procurement systems tend to apply entry restrictions in the form of firm qualification schemes. It has been suggested that in a context of incomplete information about firms' capacities under the condition that technical, economic, and financial requirements defining the qualification scheme are adequate, qualification has beneficial effects on the functioning of the competitive system (Ancarani et al., 2016; Estache & Iimi, 2012; OECD, 2010). A qualification system is essentially static in the sense that once the contract is awarded it no longer acts to motivate the firm.

In a dynamic framework, supplier selection involves a further step which requires firms to provide evidence of past performance. The relevance of this issue for the efficiency of public procurement has been a topic of policy debate at the EU level and has led to the introduction of a "company rating" as a legal public procurement regulation tool (24/2014 Directive) and to the adoption of different schemes in national legislation.[4] The importance of firms' past performance–as an instrument to prevent opportunistic behavior by the winning bidder and to improve the design of public procurement transactions–has been addressed in the literature from different perspectives. For example, Doni (2006) develops a theoretical model in which the introduction of contractor reputation in the contract award procedure has a positive effect on the quality of the service provided by the winning firm. Spagnolo and Dini (2005) and Dellarocas et al. (2006) survey and discuss the merits of using reputation based on on-line feedback mechanisms to prevent contractor opportunism while Chassang and Ortner (2019) consider a dynamic approach to repeated procurement to understand the role of "minimum bid requirements" on procurement outcomes.

[1]For instance, Bosio et al. (2020) who employ a sample of 187 countries found that restricting the discretion of the procuring agents improved procurement outcomes only in countries with low public sector capacity.

[2]In general terms, in an open procedure all interested eligible firms can respond to calls for tender published by administrations; in the restricted procedure the only firms eligible to submit bids are those invited to do so based on selection in a prequalification phase. For a detailed overview of all procedures provided for by EU directives, see CMS (2017).

[3]Under the lowest price criterion or "first price auction" procedure, the contract is awarded to the firm offering the lowest price as long as that firm is considered "reliable" according to the regulations governing abnormal tenders. In the case of the economically most advantageous criterion or scoring rule auctions, the tender call includes other parameters such as the quality of the work or the time for completion. A discussion of the pros and cons of the different criteria is provided in OECD (2016). For more details on auction formats provided for by Italian regulation, see Decarolis and Giorgiantonio (2014).

[4]For a comparative review of different models of "company rating" see Castellani and Decarolis (2017) and Galli and Ramajoli (2017).

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Building on some experimental evidence, Spagnolo (2012) shows that reputation can be designed to stimulate rather than hinder new entry and to guarantee high quality contract fulfillment. Decarolis et al. (2016) suggest that announcing the use of a reputational index based on objectively measured past performances when tendering public procurement contracts has a strong influence on efficiency.

The study by Coviello et al. (2018) investigates the role of reputation using econometric techniques and data for a sample of Italian public works contracts. The authors show that discretion increases the probability of the same firm being a repeated successful bidder and does not have a negative effect on procurement outcomes. Guccio et al. (2012) show that in a competitive tendering process, opportunistic behavior affects the firm's performance, suggesting that the role of reputation in contract award might prevent both underbidding and subsequent contract renegotiation.

Assessing the role of reputation as a selection criterion to reduce the risk of incomplete contracts (primarily, cost overruns) requires data on execution (measured by the firm's past performance). However, these data do not capture whether cost overruns are the result of the firm's inefficiency or the firm's opportunistic behavior.

The present paper contributes to this literature by investigating whether and how including firm reputation in public procurement decisions affects the final cost of the contract. We recognize that these issues depend on the behavior of both the parties to the contract and the nature of the contract (e.g., Herweg & Schmidt, 2020). We propose a simple theoretical framework to analyze the behavior of an unspecified procurer under general conditions. We assume a broad distribution of potential suppliers with heterogeneous skills and bidding strategies to identify the type of supplier most likely to win the contract under different selection rules. We develop an agent-based simulation model to provide a simplified representation of an artificial public works contracts market system with some specific features such as competing firms' technical skills and unobservable bidding strategies. We then define a statistical index to proxy for the bidding firms' reputations, and show that under realistic conditions using reputation as a selection criterion allows authorities awarding public contracts to achieve a more efficient procurement process. This index relies on widely available information, and hence is easy to compute under a wide range of conditions.

To the best of our knowledge, this study is the first attempt to use an agent-based model (ABM) in the literature concerning public procurement. The ABM methodology has two major advantages in our context. First, it allows to represent an economic phenomenon–in our case the procurement procedure–as a complex system populated by heterogeneous agents which behave and interact virtually as they would in a complex, real environment (see, among others, Dosi, 2012). Agent-based simulations do not aim at replicating specific real-world cases in detail, rather they constitute a *Gedankenexperiment* to explore the nontrivial implications of existing or potential interactions among the actors in complex systems. Second, agent-based simulations allow the arbitrary choice of the environmental and behavioral characteristics of the simulated system including those not empirically observable and the construction of several scenarios to test the consequences of different regulation setups (see Dosi et al., 2018).

Thus, an ABM simulation methodology enables generation of a virtual copy of the system of interest which allows comparison between the properties of a baseline configuration and those generated under different specifications in order to assess their effectiveness with respect to the desired goals. The computational nature of the model allows evaluation of the final results and extraction of the policy implications of the different model elements (Valente, 2017). The capacity of ABMs to investigate hypothetical conditions such as those resulting from potential-but-never-applied policies has resulted in wide adoption of this methodology by scholars investigating the effects of potential policies (see e.g. Bleda & Valente, 2009; D'Orazio, 2019; Biondo et al., 2020) or analyzing complex

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or one-off events for which traditional approaches cannot be used due to lack of sufficient data (e.g. Di Maio & Valente, 2013; Samitas et al., 2018).

In our case, the use of ABMs allows us to analyze a large number of non-linear interactions among multiple heterogeneous agents and stochastic elements. Bidding firms are assumed to have different technical skill levels which are likely to affect their ability to fulfill the contract at the agreed cost. Firms are assumed also to have a propensity for opportunism, that is, to underbid to obtain the contract and then subsequently overcharge to increase their profits. Skills and opportunism are both features which are not observable by the awarding authority; the only information available to them is that provided in the bid submitted by the firm and the actual costs of past contracts. For these reasons, firm reputation built over time provides a useful guideline for the awarding authority.

The remaining of the paper is organized as follows: Section 2 describes the model structure, Section 3 discusses the model properties and investigates the effects of different model configurations, and Section 4 provides some concluding remarks.

2 | MODEL DESCRIPTION

The model[5] includes two types of actors: (i) a set of firms competing for a public work contract, and (ii) a contracting authority trying to select the best (lowest cost) firm. The actual cost of the completed contract will depend on the winning firm's features and random environmental conditions. The awarding authority cannot identify the separate contribution of each element to the final cost; it can only observe the submitted bid price and the final cost charged by the winner of the contract. The selection of the winner depends therefore only on the bids submitted by competing firms, while the actual final cost of the work can be influenced by winner opportunistic strategy and by external events taking place during the execution of work.

Each simulation run includes a sequence of time steps, each representing a public contract to be awarded and concluded. Our model assumes a large number of contracts offered sequentially in a market populated by multiple firms. To simplify the analysis and since we are not concerned with industrial dynamics related issues, we assume that the number of firms remains constant through the various steps.[6] At the end of the simulations, we collect the final values generated in each step and assess the influence of specific conditions. In each step, all firms submit a bid but only one is awarded the contract. In principle, the work set out in the contract should be executed at the cost specified in the bid; in practice, there are often cost overruns which are charged to the awarding authority. In our model and in line with the literature, cost overruns can be due to: (i) unforeseen technical difficulties encountered by the contractor during execution of the work, and/or (ii) costs omitted opportunistically from the bid and charged to the contractor as "unexpected contingencies" on the basis that it is both difficult and time-consuming to distinguish genuine from false contingencies.

In order to assess the effect of reputation we assume the worst scenario which means that the contracting authority is never able to distinguish between the real and false reasons for overruns. We want to investigate whether it is possible to punish opportunistic firms and favor those that claim legitimate extra costs.

[5]To facilitate understanding and replicability of our model we adopt a publicly available general platform available at www.labsimdev.org Valente, 2008. The model code, the configurations presented, and the instructions for how to replicate the results are available at https://www.labsimdev.org/download/Models/FGRV_Procurement/ModelPublicProcurement.html.
[6]However, in our simplified set up this assumption is not far removed from reality where the number of competing firms tends to be fairly stable. For example, in Italy the number of firms in the market is determined by a qualification system.

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In real cases the actual distribution of opportunistic tendencies and technical skills among firms are difficult to observe. However, we are interested in assessing the capacity of the proposed awarding system to effectively perform under the worst conditions for the awarding authority. For this reason, we impose the most challenging setup assuming that opportunism and skills are perfectly inversely distributed across firms. Every bid will have the same submitted price resulting from different complementary combinations of skills and opportunism. Only after the selection of the winner and the conclusion of the works the firms' behavior will be differentiated: those with higher opportunism (and lower skills, in our setting) will claim higher overruns on top of possible legitimate extra costs in respect of firms assigned with lower opportunism (and higher skills). Such setting provides the worst possible challenge for an authority unable to assess firms' technical capacity before the selection nor the legitimacy of overrun claims after the conclusion of the works. Our results show that the awarding authority is able to select the best firms (i.e., those submitting the lowest bids) probabilistically by relying on their reputation that effectively provides a way to reduce information asymmetry between the two parties to the contract.

To proxy for reputation we use an index based on the record of claims for cost overruns by winning firms, whatever the motivation for claiming the extra costs. The index relies on the statistical differences between the two above-mentioned case–that is, genuine unexpected costs and opportunistic extra costs–and allows the awarding authority to select the most efficient and least opportunistic firm. In Sub-Sections 2.1–2.4 we describe the model variables and their formal representation.

2.1 | Bid price

Each firm at each time t computes its bid price. For simplicity, we assume that all firms offer the same quality of work and the only difference is the bid, expressed as a rebate on the reserve price.

Equations (1)–(4) describe the steps defining the firm's bid price. Equation (1) estimates the real cost that the firm expects to bear if it is awarded the contract. This cost is computed by the firm based on a self-evaluation of the skills required to perform the work expressed as a discount on the reserve price. Formally:

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

where C is the reserve price and S_i is a coefficient expressing the firm's technical skills with values ranging from 0 if the firm is unable to reduce the cost below the reserve price to 1 if the firm is able to deliver the contract at zero costs.[7] Equation (1) shows that firms with higher skills S_i generate lower estimated costs.

The firm computes the rebate after estimating the expected production cost:

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

[7]The coefficient for skill level includes the firm's desired level of profit. For simplicity we assume that for the contracting authority there is no difference between a highly skilled firm which is able to perform the contract at a low cost despite seeking a high profit, and a less skilled firm that will accept a lower profit.

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Equation (2) shows that the estimated rebate R^{Est} ranges from 0 if the firm expects the costs to be the same as the reserve price ($C_i^{\text{Est}} = C$) to 1 if the firm estimates zero costs ($C_i^{\text{Est}} = 0$).[8]

The estimated rebate based on the firm's estimated cost may be increased opportunistically to increase the chances of being awarded the contract while planning to claim fictitious extra costs after the execution of the contract.

Formally:

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

In Equation (3) the higher the parameter R_i^{Opp}, the higher the rebate R_i, and hence the higher the probability of winning the contract. Thus, parameter R_i^{Opp} denotes the firm's propensity to exploit asymmetric information, that is the inability of the contracting authority to distinguish between justifiable cost overruns due to genuine unexpected difficulties, and opportunistic cost overruns.

Recall that our model is designed to assess the effects of different degrees of opportunism among competing firms but not the origins or importance of such behavior. Therefore, we assume also that firms' adopt fixed and constant levels of opportunistic rebate. This assumption clearly eases interpretation of the results although in the real world the tendency to resort to such behavior could change over time. However, since our aim is to investigate the mechanisms linking certain conditions to specific results, what matters is the relative distribution of firms adopting the opportunistic behavior we control for.

Equation (4) shows that the bid price is computed discounting the rebate from the reserve price:

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

For simplicity, we assume that the firms' skills and opportunistic attitudes remain constant through time, that is, across each simulated bidding round, and therefore that the rebate and final bid of each firm also do not change through time.

2.2 | Final cost and reputation

The bid price is the only relevant parameter for the award of the contract. Once the work has been completed, the authority evaluates the firm's performance taking account of the final cost charged by the firm, including both the bid price and possible overruns.

Equation (5) shows that the final cost C^{Final} is computed as the bid price B_i augmented by the extra costs $EC_i[t]$ which are differentiated for each simulated time step as indicated by the time index.

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

The extra costs $EC_i[t]$ is a core element of the model including both the opportunistic rebate and legitimate claims for possible unexpected cost overruns incurred during execution of the contract.

[8]It can be noted that we assume that the level of estimated rebate is identical to the skill level. We prefer to use two notations to indicate the different nature of the variables represented. Future versions of the model could include different skill-rebate relations.

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Formally, Equation (6) expresses the composition of the extra costs which we assume it is impossible for the awarding authority to observe separately:

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

where:

- R_i^{opp} is the opportunistic rebate reducing the bid price which the firm plans to charge strategically as an extra cost if it should win the contract;
- *OR[t]* is justified cost overruns due to unexpected events during execution of the contract. This is modeled as a random variable drawn from the absolute values of a normally distributed stochastic function centered on 0 with variance σ: $\text{OR}[t] \sim |\text{N}(0, \sigma)|$. Consequently, justified costs overruns are always non-negative. They are equal to 0 if $\sigma = 0$, and follow a random distribution modeled as the positive axis of a normal random variable if $\sigma > 0$.

While in the real-world the awarding authority generally is able to verify, at least partially, the plausibility of extra costs (and potentially to challenge them),[9] here for simplicity we assume the extreme condition that the contracting authority is not able to distinguish planned opportunistic extra costs from legitimate cost overruns. Consequently, the only way that the contracting authority can infer the reliability of a firm is to compare the final cost claimed by the contractor to the original bid with no consideration of the possible motivations for any difference between these two values.

The central question of this work is to identify a strategy that the contracting authority could adopt to identify opportunistic behaviors without direct information on firms' activities. We investigate this by assuming that the contracting authority keeps a register recording the performance of contractor firms over time, and associates each firm to an index of reliability called reputation, which is updated every time the firm completes a contract.[10] In the case that there are separate records kept by several different authorities for example, in different geographical areas, the information managed by each contracting authority is available to all authorities involved in the public procurement system. We do not consider the practical aspects involved in maintaining these registers; rather, our aim is to investigate whether they could be an effective tool to limit firm opportunism and, consequently, reduce the costs of public procurement.

We assume that each firm's reliability index is computed based on cumulative evidence on its performance in each contract through multiple tender rounds.[11] At each time step the winning firm's reputation index changes according to Equation (7):

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

where:

[9]For instance, Italian legislation puts strict limits on renegotiation of contracts and specifies the conditions where it is allowed (e.g., unforeseen contingencies, technical changes to respond to new rules, etc.), the maximum amounts allowed, and the authorization procedure required.

[10]At this preliminary stage we are interested in showing the general property of our proposal and ignore possible difficulties of implementation related to managing this type of register, such as the management of new firms with no contract history.

[11]For simplicity, we assume that each tender is identical with the same reserve price; however, varying the contract value and/or the reserve price would not change the results discussed below.

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$T_i[t]$ = the reputation index at time t
γ = the weight assigned to the past value of reputation
B_i = the firm's bid
$C_i^{\text{Final}}[t]$ = the final cost charged at the end of the contract.

The reputation index is based on the ratio between the price quoted to win the contract and the actual cost charged at the conclusion of the contract. Equation (5) shows that the final cost can be equal to or higher than the bid price such that the lower the ratio $B_i/C_i^{\text{Final}}[t]$ the higher the final cost with respect to the bid price. The reputation index takes a maximum value of 1 if the final cost is the same as the bid price. The functional form describes a weighted average of the values in past contracts where parameter γ is the awarding authority's exogenous preferences which reflect the relative importance of the past values compared to the most recent information. If $\gamma = 0$ the firm's reputation is denoted by the ratio $B_i/C_i^{\text{Final}}[t]$, that is, the information collected on the most recent contract executed by the firm; if $\gamma = 1$ the firm's reputation has not changed and is equal to the initially assigned value. For intermediate values of γ, at any time step reputation varies with a smoothed past and newly recorded performance level dynamics. The expression for the reputation means that when the number of contracts awarded is sufficiently large, the index approaches the expected value of the bid to final cost ratio. We assume that all firms have identical possibilities of encountering genuine unexpected difficulties during the execution of the work which result in legitimate extra costs. Therefore, firms that systematically engage in opportunistic underbidding and overcharging additional costs on top of any legitimate extra costs, can be expected to have a comparatively lower reputation index even though the contracting authority cannot assess the validity of each individual claim.

2.3 | Selection procedure

We assume that the contracting authority will choose which firm is awarded the contract by taking account of firms' bid prices and reputation indexes, and a random factor for contract characteristics such as specialist skills required, location, timing, etc. The proposed selection mechanism ensures that the probability that a firm will win the contract increases with its rebate and reputation.

Formally, at each time step firms are assigned an index based on their reputation and rebate, which can be considered a sort of competitiveness:

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

where:

a = a parameter of the relative importance of the firm's reputation index with respect to the rebate
b = a parameter representing the degree of competition
$T_i[t-1]$ = the firm's reputation index
R_i = the firm's rebate.

The competitiveness index then is normalized to provide the probability of being selected associated to each firm as shown in Equation (9):

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

The use of a probabilistic choice reflects implicitly other aspects of the contracts not entirely reflected in the bid price.

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To sum up, the procedure followed to select the winner of a competitive tender is: (1) each firm computes its rebate taking account of its skills and opportunism, (2) the awarding authority computes the firm's probability based on this information and the firm's reputation index, (3) the awarding authority decides randomly on a firm based on those probabilities.

Equation (8) shows the range of possible conditions based on the results of simulations including different parameter values. Parameter a determines the relative importance of reputation with respect to the rebate. If $a = 0$ the contracting authority ignores reputation and considers only the rebate as the criterion for awarding the contract. If $a = 1$ the reverse applies that is, the contract is awarded on the basis only of the reputation index. In general, for intermediate values of a, both criteria are more or less relevant for assessing the tender winner.

The model allows for different degrees of concentration of the probability of being awarded the contract, depending on the degree of competition represented by parameter b. The probability for top-ranked firms (firms with the highest competitiveness index) is much higher for higher values of b.[12]

A high level of b suggests a highly competitive market where the chance of being selected is restricted to only a few top performing firms. In contrast, a low level of b is indicative of a less competitive market where over repeated draws a larger number of firms will be selected. In that latter case, the probability is spread more evenly across all firms although the best firms still have a comparatively higher chance of being selected.

2.4 | Pre-selection

The general selection mechanism described above can be applied in different conditions. In initial experiments presented below we will assume all firms in the model participate to the selection. In one set of experiments we will instead assume that before the selection the awarding authority operates a pre-selection removing from competition the firms considered with low reputation. These experiments are meant to evaluate whether the reduced number of competitors can instigate a general increase in bid prices.

The underlying idea is that in a context where there is a large number of competitors the firm proposes the largest rebate compatible with its capabilities represented by its skill S_i. However, if the number of potential competitors is reduced, the size of the rebate will also be reduced because the firm will assume that it will be easier to win the contract due to a smaller pool of competitors.

Formally, in the experiments with pre-selection we replace Equation (1) with Equation (10):

$$C_i^{\mathrm{Est}} = C \times \left(1 - S_i^*\right) \tag{10}$$

where, $S*_i$ is the skills related to the pre-selection stage:

$$S_i^* = S_i\left(1 - \frac{N - N_s}{N - 1}\right)^z \tag{11}$$

where:

N = the total number of potential bidders

[12]When we considered a set of firms with varying levels of reputation, different rebates and a given level of a, and computed two sets of indices $I_i[t]$ using two different values for b but with the same index, the values of b did not affect the firm rankings.

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N_s = the number of bidders with a high reputation index admitted after pre-selection

z = the behavioral parameter whose value (assumed to be positive) expresses the relevance assigned by the firm when making its bid to the level of competition.

The lower z, the smaller the perception of competition, meaning that the firm will not increase its bid price significantly even in the case of a very small pool of competitors. In contrast, the higher z, the larger the effect of perception of a low level of competition on increasing the bid price.

Equation (11) shows that if the set of potential N bidders is restricted to smaller selection of N_s firms, the rebate will be lower and the bid price will be higher.

3 | MODEL PROPERTIES

Although our theoretical model has a relatively simple functional structure it involves several non-linear interactions among many agents and complex stochastic elements which are partly endogenous and are cumulated across time. To assess the model properties, we conduct numerical simulations based on assigning different values to exogenous parameters such as firm skills, level of opportunistic rebate, relative weight of reputation and rebate, degree of market competition, and the behavioral parameter. This allows us to derive insights to interpret real-world evidence and propose some policy implications based on identifying the mechanisms generating the results. In particular, we investigate the role of reputation in the performance of public contracts. Our main results support the hypothesis that using a simple reputation index based on observed past results would improve the capacity of the awarding authority to select the most cost-effective firm.

To test our hypothesis, we present the results from simulations with increasing levels of complexity to highlight the contributions of the model's individual elements to the overall results.

Table 1 reports the relevant parameters—either system- or firm-related—affecting the model results.

A simulation run consists of a sequence of time steps, each representing a competitive tender for a contract comprising the following operations:

1) computation of the probability of each bidding firm to win the contract (see Equation 9)
2) random selection of the winner according to the firm probabilities
3) computation of the final cost of the contract for the winning firm (see Equation 5)
4) updating the winning firm's reputation index
5) updating several statistics such as each firm's number of previous contracts, final cost for the period, etc.

As the simulations proceed, the winning firm's reputation index is updated depending on the final cost charged. Consequently, for the time steps following execution of the contract, the probability that the winning firm will be selected is modified according to the change in its reputation index. Thus, one of the results relates to the dynamics of the firm's reputation values which, starting from the same initial value, changes during the simulations reflecting the performances of the winning firms.

After a large number of time steps,[13] we can evaluate the model performance on the basis of the observed results for example, by comparing the relation between the number of contracts awarded to

[13]Following the approach generally adopted in the economics literature on equilibrium conditions, we generally report the limit distributions to which the initial state converges and ignore the speed of convergence. However, since our analysis is important empirically, we devote a separate paragraph to evaluating the speed and robustness of the results.

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TABLE 1 Relevant parameters of the model.

Label	Level	Description	Eq.
C	Market	Reserve price	(1), (2), and (4)
N	Market	Number of firms	(11)
S	Firm	Skill level ranging uniformly from 0 to 1	(1)
R_i^{opp}	Firm	Opportunistic rebate, which firms plan to charge strategically as an extra cost in the case they win the contract	(3) and (6)
Σ	Market	Variance of the normal random variable resulting in the percentage of objectively justified extra cost	(6)
$T[0]$	Firm	Initial level of reputation for the firms, to be updated for winners during the simulation run	(7)
γ	Market	Weight assigned to the past value of reputation affecting its speed of adjustment when completing a new contract	(7)
a	Market	Parameter representing the relative importance of reputation with respect to rebate The complement to 1 is the elasticity of the reputation index to the rebate	(8)
b	Market	Parameter representing the degree of competition. The higher this value the higher the probability of selecting the best firm	(8)
N_s	Market	Number of bidders with the highest reputation	(11)
z	Market	Elasticity of rebate to the degree of competition representing the importance that firms assign to the degree of competition when making their bids	(11)

each firm and its skills. This allows us to evaluate whether firms with higher skills are more or less likely to win contracts compared to firms with lower skills, and to assess the role of reputation.

To better appreciate the properties of the proposed index and the mechanism underlying its effects we adopt an extreme assumption for the set of competing firms. We consider a large number of firms which results in visually dense graphical representations that clearly highlight the model properties. We assume also that the simulated firms present a perfectly negative correlation between skills and opportunism, with the proportions of these features varying across their entire spectrum. Obviously, this is an unrealistic assumption but provides the toughest possible environment to test our proposed reputation index since, given the equations presented above, this assumption generates identical bids for all firms. They are differentiated because each firm is assumed to charge a different level of unjustified, opportunistic extra costs perfectly matching the different skill levels required to produce identical rebates.

Below we present the results generated by the model starting from an extremely simplified version in order to familiarize the reader with the class of results discussed. Subsequently, we present a sequence of scenarios gradually activating all aspects of the model. In addition, we report some results aimed specifically at demonstrating the robustness of results and the speed of convergence from the initial configuration to the final distribution. Finally, we present two variations of the model as examples of possible extensions to our analysis. The first refers to the relation between use of reputation and implicit reduced competition. The second refers to the dynamic effect of reputation on the probability of the firms' survival in a market with entry and exit of firms. Below we list the scenarios and the related figures.

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Scenarios	Figures
Scenario 1: Test case where firms show no opportunism, there are no overruns and the awarding authority does not consider reputation; effects of competition	Figures 1–3
Scenario 2: As above plus opportunism perfectly correlated to skills	Figure 4
Scenario 3: As above plus use of reputation index by awarding authority	Figure 5
Scenario 4: As above plus presence of genuine extra costs	Figure 6
Robustness and convergence: Extensive tests of results of scenario 4	Figures 7 and 8
Scenario 5: Extension on reputation and competition	Figure 9
Scenario 6: Extension on reputation and dynamic selection	Figure 10

Specifically, scenario 1 (1a, 1b and 1c) provides preliminary evidence based on a very simplified configurations, aimed at clarifying the individual effects of the model's core elements. The remaining scenarios describe progressively more complex configurations in order to assess the role of reputation.

3.1 | Scenario 1: Skills and competition

Initially, we consider the model results when the index of reputation is ignored by the awarding authority, to be used as baseline comparison version in order to better appreciate the effects produced by the use of reputation as a criterion to assign contracts. In this initial case, the contracting authority evaluates the firms only on the basis of their bids, so that firms with the highest rebate have a higher probability of winning the contract. Formally, this is implemented imposing parameter $a = 0$ in Equation (8).

3.1.1 | Skills only

In this first exercise we assume also (again, for comparison purposes) that: (i) firms do not apply any opportunistic rebate (parameters $R_i^{\text{Opp}} = 0$ for each firm, see Equation 3), (ii) the probability of unexpected events is null, so that the final cost depends only on the firm's skills, and therefore, equals the firm's bid.

To facilitate interpretation of the results we impose a specific distribution of skills across the firms. We assume that all firms are differentiated by equally distanced skill levels within a range between 0% and 50%, generating an equally distribution of rebates on the reserve price. This assumption allows us to rank the firms and identify the relation between their skill level and performance under the institutional setting adopted for each exercise.[14] Table 2 reports the parameter values for initialization of the simulation.

[14]There is no empirical evidence on the distribution of skills, so this hypothesis cannot be claimed to be realistic but also cannot be rejected. We are interested in the relation between the selection criteria and the individual firm properties, and so our results are not affected by any distributional assumptions about the population of firms.

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TABLE 2 Parameters of the model (values used for the initialization of scenario 1).

Label	Value	Description	Eq.
C	100	Reserve price	(1), (2), and (4)
N	1000	Number of firms	(11)
S	0–0.5	Skill level assigned to each firm, ranging uniformly from 0 to 0.5	(1)
R_i^{Opp}	0	Opportunistic rebate which firms plan strategically to regain as an extra cost if they win the contract	(3) and (6)
σ	0	Variance of the normal random variable resulting in the percentage of justified cost overruns. When σ = 0 there are no justified costs overruns, but only those depending on opportunistic bidding	(6)
b	10	Parameter representing the degree of competition. The higher this value, the higher the probability of selecting the best firm	(8)
z	0	Behavioral parameter whose value depends on the weight that the firm assigns to the degree of competition when making its bid	(11)

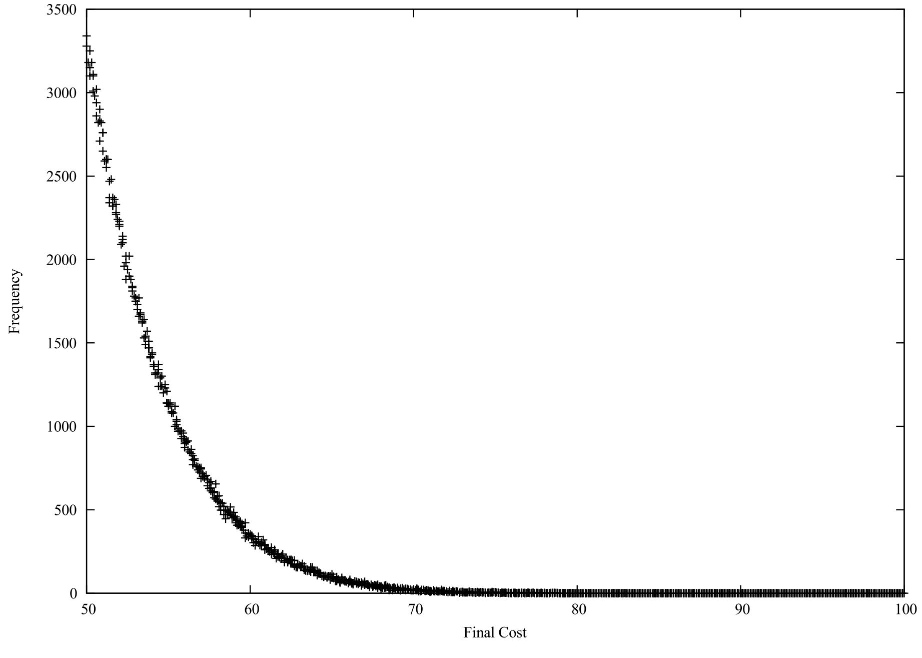

FIGURE 1 Frequency of contracts awarded distributed according to their final costs.

In this simplified setting, the rebate accurately represents the firm's technical capacity and there are no cost overruns due to unexpected contingencies. Hence, the selection mechanism used in the model can be tested to assess whether it correctly identifies the objective quality of firms.

Figure 1 depicts the data obtained at the end of a simulation run when a large number of contracts has been awarded. The horizontal axis represents the different firms ranked according to the final cost charged, ranging from 50 (50% of rebates due the maximum level of skills) to 100 (0% rebate). The vertical axis measures contract frequency (total number of contracts won during the simulation) associated to the firm reported on the horizontal axis.

The results show clearly that firms with the highest costs (lowest skills) are never selected (the reported frequency is equal to zero), suggesting that they never managed to win a contract over the

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whole simulation run. Firms with mid to low costs (mid- to high skills) correspond to increasing frequencies; the maximum frequencies correspond to firms with the lowest costs. The distribution is slightly noisy due to the random component in the selection mechanism. As noted above, this mechanism generates a higher probability that the contract is awarded to firms with the highest rebate but all firms enjoy at least an infinitesimal non-zero probability of being chosen.[15]

3.1.2 | Reputation index

It is possible also to show that the firms' reputation indexes, although not used in the simulation, correctly reflect firms' qualities that is, that the reputation accrued by each firm is proportional to its skills. Figure 2 confirms that this is the case and shows that the highest reputation is linked to firms with the highest skills.

This scenario assumes that firms do not engage in opportunistic behavior and there are no unexpected costs. Consequently, the reputation index potentially could reach the maximum level of 1 for all firms. However, only the firms with the highest skills are selected with sufficient frequency to increase their reputation value from the initially exogenously assigned value of 0.5. A few firms with intermediate level skills win contracts sufficiently often to increase their reputation from the initial

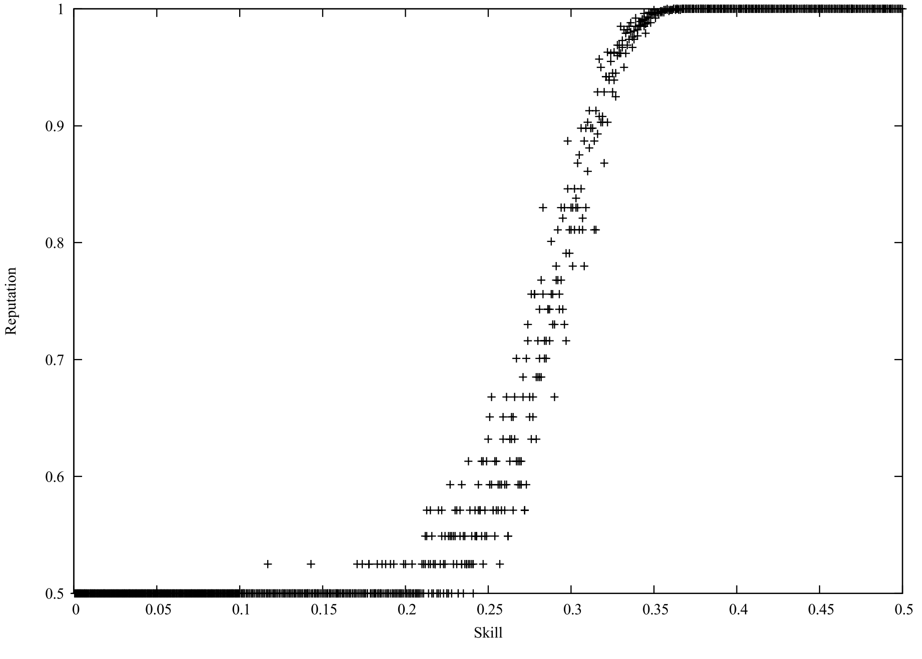

FIGURE 2 Reputation index distributed according to firm skills.

[15]In certain cases, simulations using stochastic components require multiple runs to ensure that the results do not depend on a single "lucky" run. However, although our simulations include a few random components they have a strong deterministic structure so that the results vary only infinitesimally across different simulation runs. For this reason, we skip the statistical analysis required to prove the inter-simulation stability of results. Additional evidence is provided in the simulations designed specifically to test the robustness of the results.

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value but not by enough to reach the maximum value. Low skilled firms are never tested because they never win a contract, so their reputation remains at the initial value.

3.1.3 | Degree of competition

Maintaining the assumption that firms do not behave opportunistically, we next consider the effects of degree of competition on the selection mechanism represented by the parameter b (see Equation 8). As before, the final cost depends only on each firm's skills. Thus, selecting firms with the highest skills guarantees a lower cost of contract execution.

The previous result was generated by imposing the level of 10 on parameter b which determines the concentration of the distribution of probabilities of firms in the selection procedure. To show the effects of this parameter we present the results generated along 10 simulations using values of b from 2 to 20 to show the role of this parameter in affecting the average cost paid for the work during an entire simulation run (see Table 3).

We consider the average cost charged by the winners across the time steps as indicators of overall efficiency of the setting; the higher the value, the lower the capability of the setting to select the best firm.

Figure 3 report the values for the average cost paid across the 10 different simulation settings in Table 2 differentiated for the values of parameter b set to levels from 2 to 20.

The horizontal axis represents the value of the parameter b, controlling the degree of competition, and the vertical axis is the average cost paid by the awarding authority across all the time steps in a simulation run.

We can identify the extreme theoretical values; if the best firm were always awarded the contract, the average cost will be 50 (rebate at 50%). If the worst firm always wins the contract, the cost would be 100, generated with a null rebate.

The results reported in Figure 3 show that configurations with higher values of b restrict the chances of being selected to a few, top performing firms. A low level of b means a larger number of firms will be selected, with better chances for firms with less than optimal skills, and hence higher costs. This result shows that higher selection pressure rewards firms with the highest skills which, in the absence of opportunism, correspond to lower costs.

3.2 | Scenario 2: Effects of opportunism

The effectiveness of the level of competition for identifying the best performing firm is reduced, and potentially disappears if the firm acts opportunistically.

In scenario 2 we assume that firms with lower skills increase their rebate and plan to increase the final costs beyond the contractual agreement.

TABLE 3 Values used for parameter b in scenario 2.

Label	Value	Description	Eq.
b	2, 4, …, 18, 20	Parameter representing the degree of competition. The higher this value the higher the probability of selecting the best firm. 10 simulations using different values for the parameter from 2 to 20	(8)

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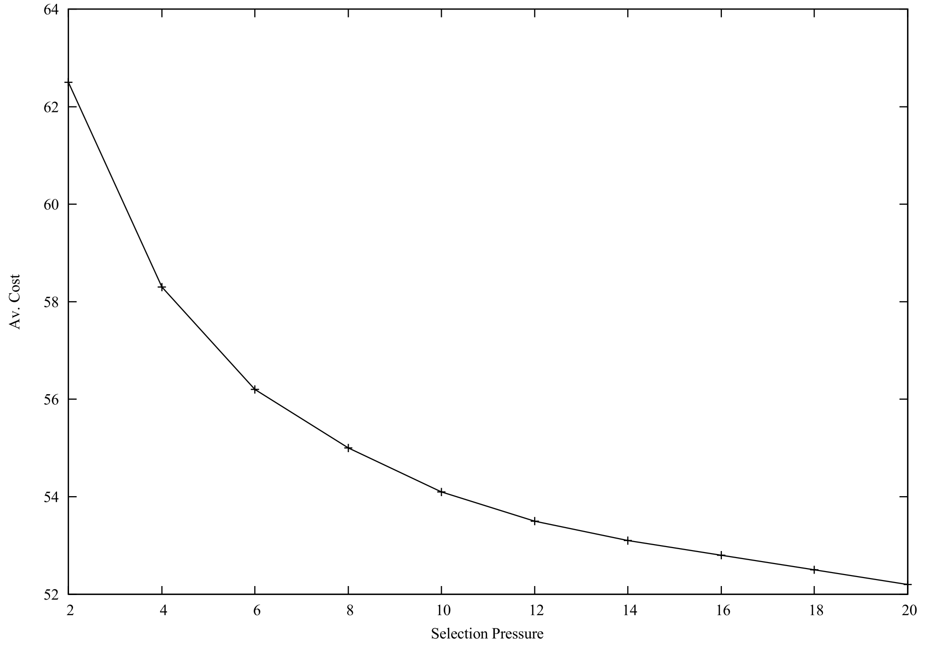

FIGURE 3 Average final cost of awarded contracts and degree of competition.

TABLE 4 Values used for variable R_i^{opp} in simulations.

Label	Value	Description	Eq.
R_i^{opp}	From 0.5 to 0	The opportunistic rebate perfectly matches the complement to 0.5 of the skill S_i of the firm, so that each firm produces the same bid level: $R_i^{\text{opp}} = 0.5 - S_i$	(3) and (6)

To generate the most challenging context for the awarding authority, we assume that firms apply a level of opportunistic rebate that is the inverse of their skills. Recalling that skills range from 0 to 0.5, we assume that the firms adopt a differentiated opportunistic rebate of the exact amount required to produce the same rebate offered by the most skilled firm. That is, a firm with a skill value S_i is assigned an opportunistic rebate $R^{\text{opp}} = 0.5 - S_i$ so that the resulting final rebate is identical for all firms (see Table 4) although the *composition* of the rebate is uniformly differentiated across firms from the best (0 opportunistic, 0.5 due to skills) to the worst (0.5 opportunistic, 0 due to skills).[16]

Under these conditions where every firm submits the same bid, the awarding authority has no possibility to distinguish between a genuine rebate which will result in a lower final cost, and an opportunistic rebate which eventually will lead to a higher final cost. Notice that the level of competition pressure has no effect since the submitted bids are all identical.

Figure 4 reports the same data as in Figure 3, that is, the average cost for different degrees of competition, with firms adopting differentiated opportunistic rebate. Unsurprisingly, the average cost charged by the winners is much higher than in the case without opportunistic behavior. In contrast to the previous case, the average cost does not change with the degree of competitive pressure because

[16]The assumption about the distribution of opportunism lacks empirical support. Similar to the assumption about the distribution of skills, we adopt it to facilitate interpretation of the results which due to their nature are not affected by this assumption.

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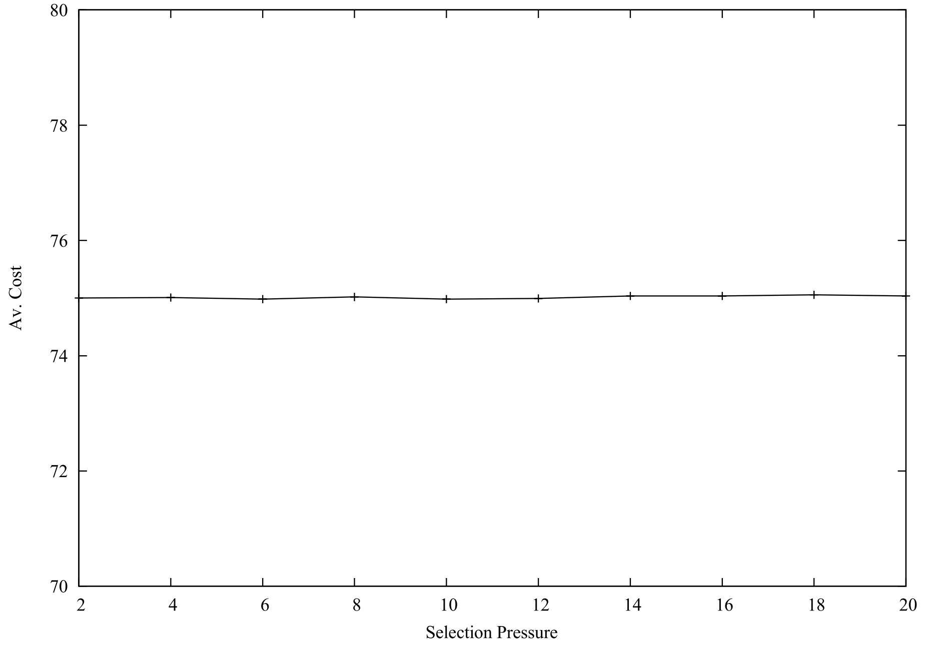

FIGURE 4 Average cost for different degrees of competition in the presence of uniformly distributed opportunistic rebates perfectly balancing the skill level so that each firm produces identical bids with a different mix of skill and opportunism.

TABLE 5 Values used for parameter a in simulations.

Label	Value	Description	Eq.
a	0.7	Parameter representing the relative importance of reputation with respect to the rebate. The complement to 1 is the elasticity of the index to the rebate	(8)

the rebates are identical, and therefore the probability concentration has no effect on the capacity of the system to provide low costs. The average final cost paid by the awarding authority is the average cost charged by the firms selected randomly with uniform probability regardless of their skills whose effect cannot be disentangled from that due to their opportunistic strategies.

We take this result as our baseline result which in its extreme form represents the problem faced by awarding authorities when they receive bids which might be based on either genuine or opportunistic rebates.

3.3 | Scenario 3: Reputation versus opportunism

We next test the capacity of the reputation index to allow the awarding authority to distinguish bids with identical values submitted by firms with different opportunistic behaviors. We compare the number of contracts awarded across several time steps using the same configuration as in scenario 2. In this scenario we allow the selection mechanism (Equation 8) to take account not only of the bid level but also of the reputation level, setting the value of $a = 0.7$. That is, the previous configuration is modified as presented in Table 5.

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The results of this exercise are plotted by the square symbols in Figure 5 where the horizontal axis is firms ranked by increasing skill level (and hence, decreasing level of opportunism) and the vertical axis shows the number of contracts assigned across all the time steps. For comparison, we report the same data from a simulation run generated in scenario 2, where the contracting authority selects the winner considering the level of the rebates (value of $a = 0$).

Figure 5 shows clearly that use of reputation significantly increases the awarding authority's ability to identify firms adopting opportunistic behaviors. During the first-time steps in the simulation all firms have an initial identical reputation index and submit identical bids; consequently, they are chosen randomly with the same probability. However, the outcome of these early contracts changes their reputation index, and hence their probability to be selected in the subsequent time steps. If the firm charges high extra costs its reputation worsens reducing its probability to be selected. In contrast, firms with lower levels of opportunism accumulate increasingly higher reputation indexes increasing their probability of winning future contracts. Cumulatively, the most honest firms will emerge as winners more frequently than their opportunistic competitors.

Although this configuration shows that reputation can be effective, it describes a rather simplified world where cost overruns are due exclusively to opportunistic behavior. Scenario 4 tests the efficacy of reputation when honest firms face genuinely unplanned cost overruns so that their reputation is reduced even if they never intended to bid strategically below the final cost level.

3.4 | Scenario 4: Reputation and randomness

In this scenario, we analyze the results generated by a configuration where the contractual cost and the final cost may differ due to strategic opportunism or unforeseen contingencies.

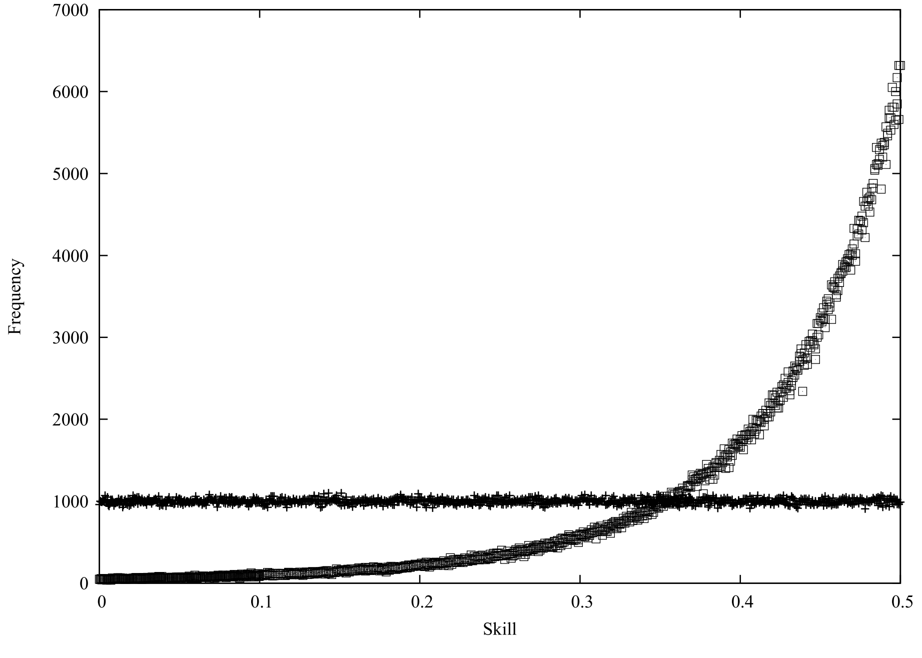

FIGURE 5 Number of contracts awarded and firm skills in the presence of opportunistic rebates and considering reputation. Comparison between scenario 2 (crosses, selection without reputation) and scenario 3 (squares, selection with reputation).

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As in scenario 3, we assume that it is not possible to distinguish between legitimate and opportunistic extra costs which is the most challenging condition for the contracting authority. Since our proposed reputation index is based on comparing the extra costs to the bid price, it might be expected that the role of reputation as a selection criterion to identify the most-effective firm would be undermined. However, we can show that even under this condition, reputation retains its selection capacity.

To prove this, we use the same configuration as in scenario 3 and we modify the parameter controlling the random component of the final cost (Table 6) which previously was set to 0, effectively preventing random events causing genuine extra costs.

In this configuration the final cost is affected by both opportunism and a random event. Assuming that it is not possible to distinguish between legitimate and opportunistic extra costs, we test whether the presence of external random noise may reduce the effectiveness of reputation as a criterion to select the best firm. Figure 6 shows that random extra costs affect the results only marginally. The axes and data are the same as in Figure 5 (cross symbols). The new data computed with random noise (square symbols) show that the two series are virtually identical, proving that using reputation to award contracts is not undermined by the presence of randomly justified cost overruns.

Even with random extra costs, reputation correctly discriminates firms claiming non-legitimate higher costs. The results show only a slight reduction in performance with firms with the highest skills winning contracts slightly less often. We can conclude that the presence of random noise and a mix

TABLE 6 Values used for variable σ in scenario 4.

Label	Value	Description	Eq.
σ	0.2	Variance of the normal random variable resulting in the percentage of objectively justified cost overruns	(6)

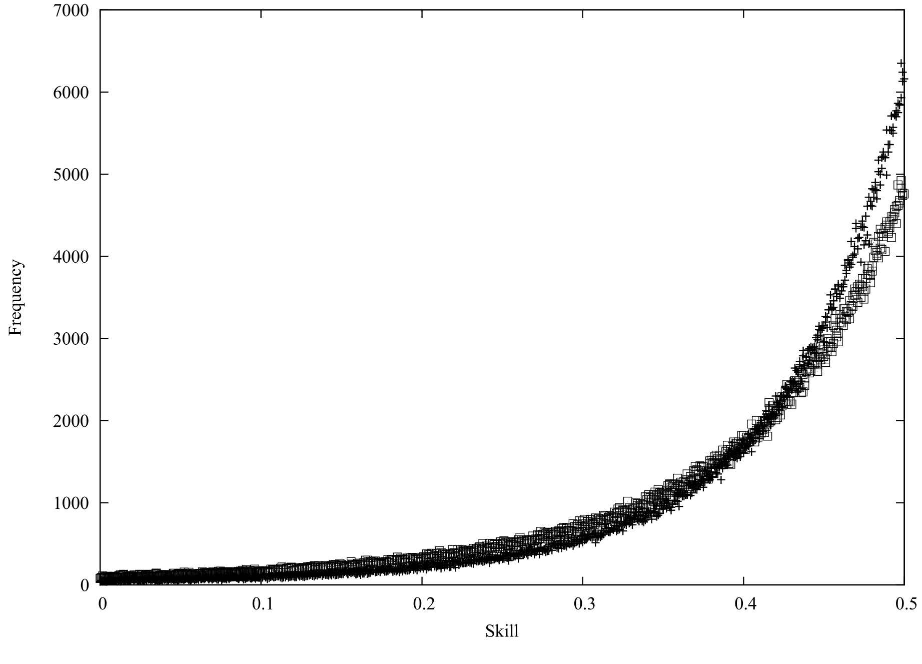

FIGURE 6 Number of contracts awarded and firm skills in the presence of opportunistic rebates and cost overruns due to random events (squares) compared to the case of cost overruns due only to opportunism (crosses), as in Figure 5.

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of genuine and opportunistic cost overruns only marginally reduces the effectiveness of the reputation index as a criterion to select the best firm. Were the contracting authority able to identify at least a small percentage of opportunistic firms this would reinforce the effect of reputation.

The results of this scenario depend on a robust statistical property. Any types of firm (more or less opportunistic) can experience unexpected events but more opportunistic firms show higher average claimed overruns (summing both genuine and opportunistic extra charges) which allows us to include this effect in the selection process. The proposed indicator offers a simple means to exploit the available information on bid price and final claimed costs. Therefore, it relies not on potentially debatable technical analysis of the claims but on the use of two publicly available pieces of information, that is the bid price and final cost.

3.5 | Convergence and robustness

In the context of conventional analytical models economists tend to limit the discussion to equilibrium properties and model stability, and ignore the system's dynamic properties that is, the speed at which equilibrium is achieved. We have followed this approach so far and presented the distributions resulting from the simulations including a large number of time steps so that the variables of interest reached a stable distribution. However, in many cases the dynamic dimensions of economic phenomena can be as important as their limit properties, and especially in the context of empirical applications. Therefore, we present additional evidence related to the speed of convergence of our main result, showing that even under the challenging initial conditions we assume, the speed of adjustment of the reputation index is sufficient for it to act as a valid policy tool under realistic conditions. We also demonstrate the robustness of our results against the random volatility of our model, and show that they are independent of the particular sequence of random values used in a specific simulation run.

In the previous scenarios, we considered a large number of firms in order to provide finer grained graphical evidence. However, the time of adjustment of the model depends on comparison of the performance of all the firms potentially winning a contract. Consequently, although an unrealistically large number of competing firms is useful to generate smooth distributions, it also implies minimal differences among competing firms and artificially increases the time required to reach a stable distribution. To test the robustness of our results and the speed of convergence in realistic conditions we consider the more plausible number of five competing firms. In line with the above scenarios, we make the same assumptions about the firms' initial features, generating the most challenging case where all firms have the same initial reputation level and make identical bids resulting from specific combinations of skill and opportunism. The robustness exercise examines whether the reputation based selection algorithm is able correctly to identify firms with the highest skills across many independent simulation runs and quickly.

To test the results for speed of convergence and robustness, we replicated 100 simulations with the configuration shown in Figure 6 (but with 5 firms instead of 1000) using different random values for every simulation run. Figure 7 reports the results for the first 100 time steps for the 5 firms. Each set of three lines represents the average value for reputation for one firm across the 100 repetitions; the firms are labeled depending on their level of opportunism. The two dashed lines represent the confidence intervals for the variable comprised between them across 100 repetitions, indicating the threshold of 95% of the inter-simulation variance above and below the average value.

Figure 7 shows that after fewer than 10 time steps the firms' reputation indexes diverge substantially. Notice the different growth rates—slower for the firms with high levels of opportunism and faster for firms with low levels of opportunism—due to the different probabilities of winning the contract.

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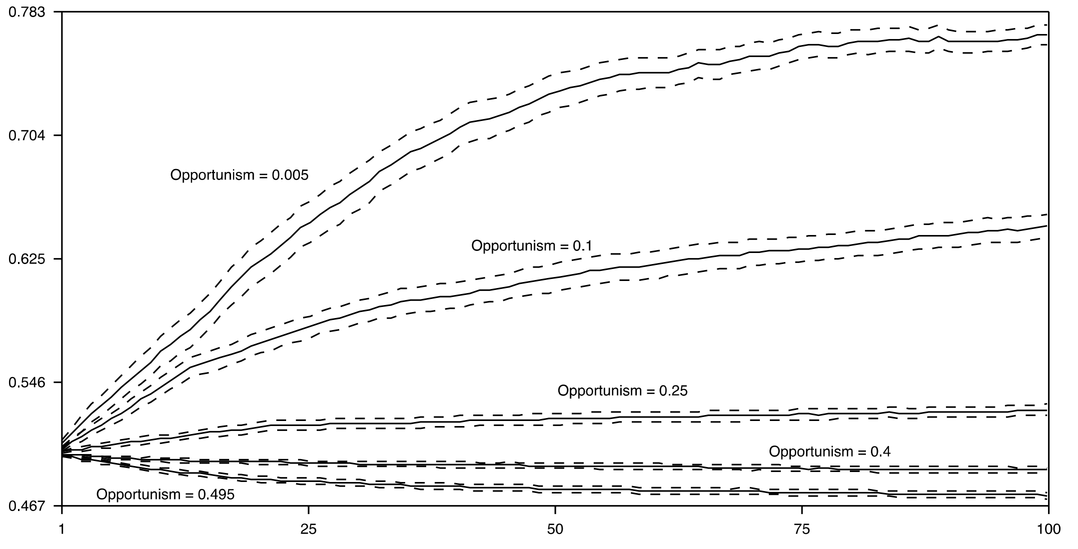

FIGURE 7 Reputation index time series for 5 firms differentiated for opportunism, reported on the labels. The skill level is set to the complement to 0.5 of the opportunism, and so all firms submit the same identical bid price. The horizontal axis indicates the time steps of the simulation and the vertical axis refers to the reputation index. Each solid line indicates the average value for one firm at each time step across 100 replications with different random values. Dashed lines indicate the confidence intervals (95% of the variance) for each average.

This is explained by the fact that firms with a low reputation index win contracts less frequently than competitors with a high reputation index, and therefore experience fewer changes (downgrades) to their reputation indexes.

Figure 8 reports the firms' capacity to win a contract. It depicts the relative share of the contracts assigned to each firm measured at six time stages in the simulations: $t = 10, 20, 30, 50, 100$, and 1000. Since at each time step the simulation awards one contract, the total number of contracts assigned up to time, for example, 20 is 20. Consequently, in order to compare the number of contracts won at different time steps, we compute their shares of contracts won by each firm at the different time.

On the horizontal axis the five firms are ranked by their skill (again corresponding to the complement of opportunism); each point represents the average value across 100 simulation runs measured at a given time step, as indicated by the pattern of the lines connecting the points. The vertical segments crossing each point indicate the confidence intervals above and below the average measured across the different simulations.

The results show that starting from the same level of reputation, the top firms rapidly differentiate, exhibiting significant more success in winning contracts after only 10 steps, as indicated by every line showing growing shares of contracts corresponding to growing skills. While more contracts are assigned and firm reputation is adjusted, the distribution rapidly converges to the long term distribution, approximated here by the values reached at the 1000th time step.

The confidence intervals confirm that there is a low level of variability across the simulations after 50 steps. This convergence indicates that the comparatively high levels of volatility in the early steps, indicated by wider confidence intervals, do not lead to bifurcated long term states.

We can conclude that the relevant model properties are robust, are not dependent on particular stochastic conditions, and emerge relatively rapidly. In particular, even in a context of extremely adverse initial conditions, the endogenously developed reputation index accurately reflects the firm's exogenously assigned propensity to engage in opportunistic bidding. The algorithm representing the

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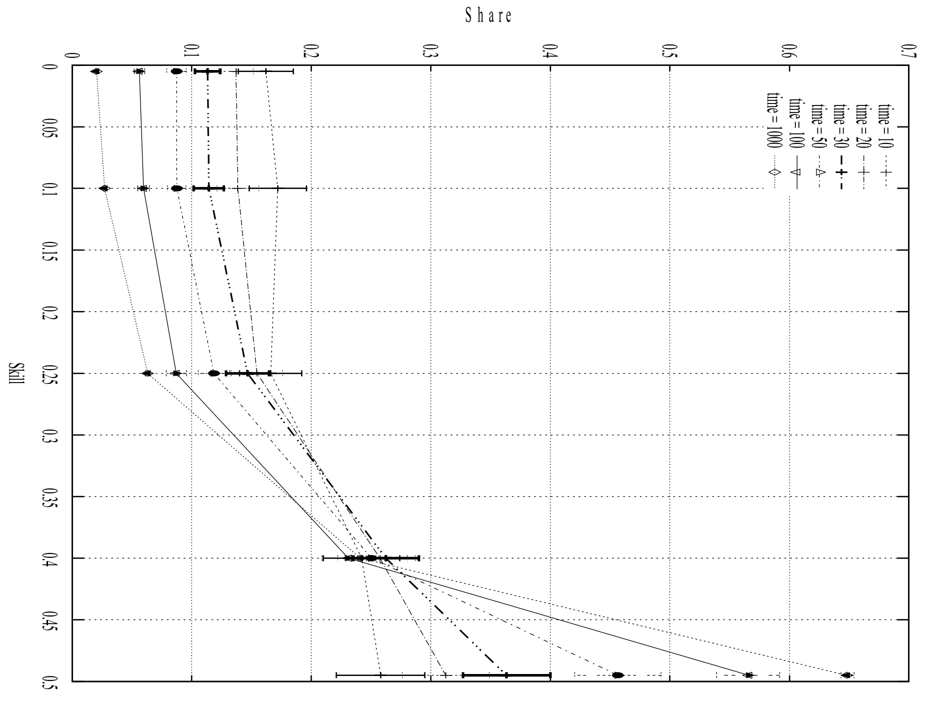

FIGURE 8 Cumulative share of contracts won by the 5 firms at different timing of the simulation runs for the same configurations as in Figure 7. The horizontal axis refers to firm skills; the vertical axis refers to the share of contracts won at a given time step. The lines refer to the different time steps and report the average values across 100 simulation runs. The vertical segments indicate the confidence intervals across 100 repetitions.

awarding authority procedure rapidly converges to reward the most efficient firm. These results are particularly remarkable because we assume the most challenging hypothesis concerning the mix of opportunism and skills, forcing the proposed algorithm to individuate the best firms among a set of competitors submitting identical bids. In the succeeding sub-sections, we explore the effects of reputation on other aspects of the public procurement market.

3.6 | Scenario 5: Reputation and effects of limited competition

Scenario 5 considers a possible counter argument against use of reputation, that firms with a high reputation index might exploit their status to increase their bid price on the basis of a reduced level of competition. To test our hypothesis, we employ an extension of the standard model as configured in scenario 4 adding a pre-selection phase where the reputation index is used to define eligibility for standard selection. That is, in this scenario we assume that only firms with a sufficiently high reputation index are allowed to tender (see Equation 11). Firms that pass the pre-selection stage and are allowed to participate in the bidding procedure are assumed to be aware of the lower level of competition and therefore will increase their bid price (i.e., reduce their rebate) by an amount proportional to the number of competitors involved in the final selection.

Formally, we adopt the same configuration as in scenario 4, using the values reported in Table 7:

This configuration tests whether the use of reputation to reduce opportunism might be counterbalanced by exploitation of reduced competition. In the extreme cases where firms either totally ignore

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TABLE 7 Values used for variable N and parameter z in simulations.

Label	Value	Description	Eq.
N_s	From 100 to 1000	Number of bidders with highest reputation admitted to the final selection; 10 simulations with values of N_s ranging from 10% to 100% of the total number of firms	(11)
z	0.01	Behavioral parameter expressing the weight that the firm assigns to the reduction of the number of competitors in making its bid	(11)

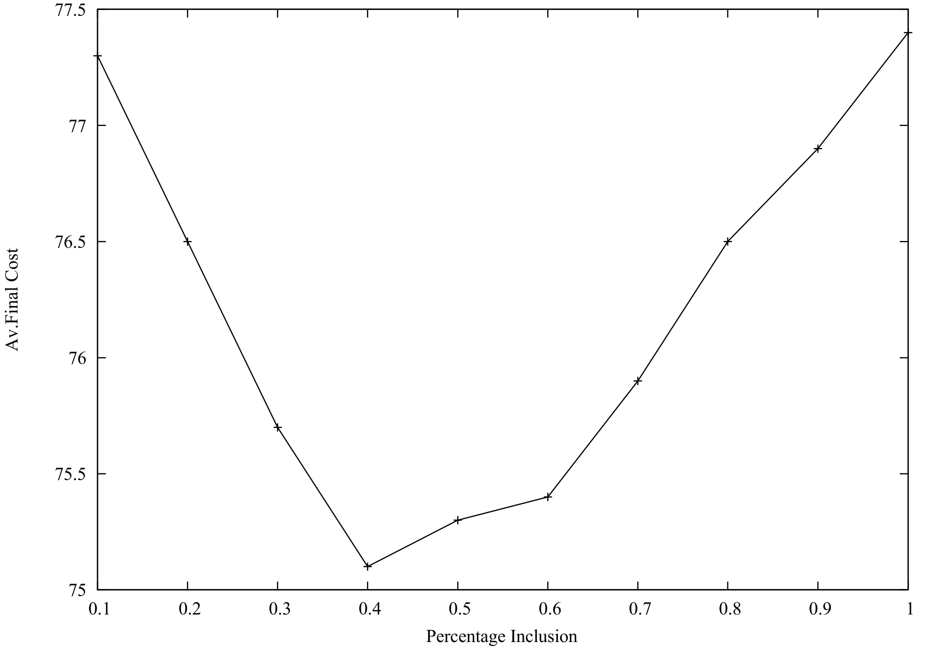

FIGURE 9 Final costs of awarded contracts and percentage of firms allowed to tender with cost overruns.

or give extreme relevance to the number of competitors (i.e., parameter z close to 0 or very high) the results are trivial. The interesting cases are those with intermediate z values.

The horizontal axis in Figure 9 refers to the share of firms eligible to tender and goes from 10% to 100%; the vertical axis shows the corresponding average final contract cost. The U-shaped curve indicates that the final cost is higher at the two extremes.

In the case of a small number of competitors, even if only firms with high reputation are allowed to compete, the very small number of firms favor very high bid prices. At the opposite end of the spectrum, if the number of competitors is very large (as without pre-selection, or 100% of firms included), the individual bids are the lowest, but the awarding authority has a much higher chance of selecting a firm with a high tendency for opportunism. Therefore, the lowest average cost is obtained at an intermediate size of pre-selection based on firm reputation. In this case, only the worst firms are excluded from bid submission and those eligible to bid are competing against a sufficiently large number of firms to discouraged excessive bid price. This means that the most efficient procurement outcomes are obtained at a reputation threshold which allows the optimal number of firms to be declared ineligible to bid due to their poor reputation.

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3.7 | Scenario 6: Reputation as an incentive

So far, we have discussed reputation as a means to identify the best firm within a fixed pool of competitors practicing a constant mix of honest and opportunistic strategies and with different levels of skills. However, using reputation in the selection process can be a significant incentive for the firm to adapt its behavior and offer the best rebate corresponding to its skills thereby reducing the level of opportunism.

To test the effectiveness of reputation in driving firms to adopt a more honest bidding strategy we re-arranged the model by including a basic representation of a population-level learning process based on a simple evolutionary dynamic. We assume that during a simulation run the set of bidding firms is modified regularly by removing the worst performing firms and adding new ones. As in the previous scenarios, each firm is associated to specific levels of skill and opportunism. However, instead of imposing the firms' skills to be perfectly complementary to their level of opportunism, in this case both values are randomly assigned at the time of entry of the firm. If the selection were neutral with respect to skills and reputation, we should observe a constant average level of skills and opportunism in the population of firms, reflecting the expected value of the random function used to assign the values for the new entrants. However, we find that the population's average level of opportunism decreases significantly over time falling to values well below the expected levels from the random initialization, meaning that the use of reputation reduces the survival probability of firms with high levels of opportunism. By a logical extension we can conclude that, were firms able to change their preferences with respect to opportunistic bidding, they would learn that this was not an effective strategy.

Formally, we assume that after a few rounds of simulated contracts one of the existing firms drops out of the pool of competitors and is replaced by a new entrant. When the replacement takes place, the system removes the firm with the smallest number of contracts awarded in the previous rounds. The new entrant is exogenously assigned a random value for skill and opportunism levels and a low initial value for reputation. The values of skill S_i and opportunism R_i^{opp} levels assigned to new entrants are drawn from a uniformly distributed random function in the range [0.0; 0.5], so that on average the typical new entrant scores 0.25 for skill and opportunistic behavior.

Figure 10 reports the average skill and opportunism levels computed across a set of 10 firms competing to win contracts across time, starting with a population of identical firms scoring 0.25 for both skill and opportunism. Every 10 contracts, the firm with the smallest number of contracts won in the previous time stage is removed from the population and is replaced by a new entrant with randomly assigned values for skill and opportunism.

The results show that the population of firms "learns" that opportunism is not a winning strategy. The falling level of average opportunism across time indicates that firms with small values of R_i^{opp} are more likely to remain in the market while competitors with high levels of opportunism are more likely to win fewer contracts and to exit the market. The average level of opportunism drops from the initial 0.25 to about 0.1 as the series stabilizes. The results show also that firms with higher skills enjoy an evolutionary advantage indicated by the population average skill, increasing from an initial 0.25 (value determined by the random choice distributed in the [0:0.5] range) to about 0.4.

4 | CONCLUDING REMARKS

In this paper, we use an ABM to analyze the role of reputation in public procurement regulation. We focused on whether the contracting authority could develop a strategy based on reputation to identify and avoid the opportunistic behavior of firms. We defined a reputation index computed on the basis

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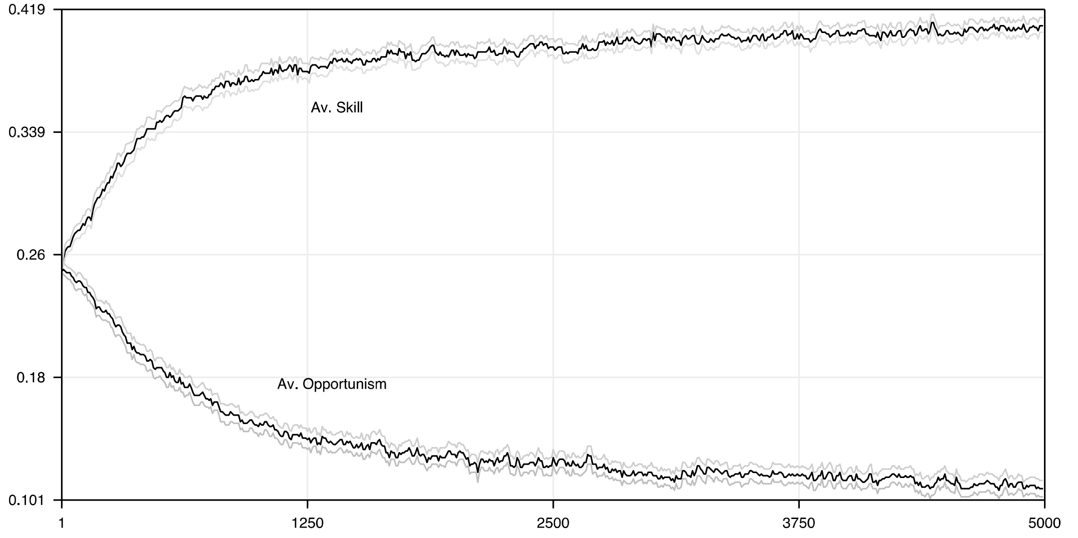

FIGURE 10 Time pattern of average skill and average opportunism in a dynamic population. The horizontal axis represents simulation time and the vertical axis represents average skill and opportunism levels. At regular intervals, firms with the lowest number of contracts won are eliminated and replaced by new entrants assigned with randomly chosen values for skill and opportunism. Black lines indicate average values across 100 repetitions of the same configuration with different random values; gray lines indicate confidence intervals comprising 95% of the variety across the 100 repetitions.

of the record of cost overruns claimed by each winning firm at the end of the contract, regardless of whether these costs were legally justified or represented opportunistic claims. We showed that under general conditions this index allows the awarding authority to: (i) select the most efficient and least opportunistic firms, and (ii) remove those engaged in frequent opportunistic behavior whose reputation has deteriorated and which are less likely to win contracts.

Our findings have some important implications for policy. First, they show that a legislative framework which includes reputation in the award of contracts is beneficial. Current debate on public procurement in the EU tends to concur. It is particularly relevant in countries such as Italy where the Procurement Code (the Legislative Decree n.50/2016, as successively modified) has introduced a reputation mechanism that is, a firm rating mechanism. This rating is based on the potential contractor's past performance and can be used as a selection criterion for bidding firms and as a contract-award criterion. However, it is voluntary which could weaken the role of reputation in the award of contracts.

Second, taking account of reputation raises certain issues. The design and implementation of appropriate reputation mechanisms in public procurement interact with—and are affected by—the propensity for innovation within public administrations. Systematic inclusion of reputation would expand the set of information to be considered by contracting authorities, and would represent an important cultural innovation.

Third and building on the previous point, we tested the efficacy of an index used as a proxy for the bidding firm's reputation. This index can be computed using publicly available data that is, the bid price and the final cost charged. We show that in a theoretical context simulating the noisy conditions of real-world public procurement contracts, this index is able correctly to identify firms that opportunistically charge extra costs. Our experiment suggests that reputation could both act as an effective selection criterion and constitute a powerful incentive for firms to improve their technical skills and engage in fair competition as opposed to relying on opportunistic behavior to win a contract.

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Further developments of our model could examine whether and how firms modify their behavior in response to procedural innovations aimed at imposing a structured network allowing contracting authorities to share online information on the performance of each contract.

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