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Discrimination in Dynamic Procurement Design with Learning-by-doing

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Discrimination in Dynamic Procurement Design with Learning-by-doing*

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Abstract

We study the long-run impact of procurement discrimination on market structure and future competition in industries where learning-by-doing makes incumbent firms more efficient over time. We consider a sequential procurement design problem in which local and global firms compete for public good provision. Both firms benefit from learning-by-doing if they provide the public good in the previous period, but global firms only may be able to transfer learning-by-doing from different markets. We show when the optimal procurement has to be biased in favor of the local firm even when all firms are symmetric with respect to their initial cost distribution.

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1 Introduction

Discriminatory programs that favor local and small firms in government procurement are common in several countries. In the U.S., for instance, the Small Business Act explicitly requires that the federal government grants a significant portion of the annual procurement contracts and sales to small businesses.[1] Under the Buy-American Act, the United States Government offers a 6 percent bid preference to domestic suppliers. The European and Japanese governments do not explicitly state the formulae by which local and small bids are to be compared with foreign bids. Instead, these governments achieve favoritism by more covert methods: allowing a short time for the submission of bids, applying residence requirements on bidders, and defining technical requirements in such a way that it is difficult or impossible for foreign firms to comply (see, e.g., McAfee and McMillan, 1989; Coviello and Mariniello, 2013).

A significant literature in economics contains findings that support the desirability of these programs. Several papers have shown that bid preferences programs in favor of weak (local and small) firms may lower government procurement cost (e.g. Myerson, 1981; McAfee and McMillan, 1989) and achieve distributional goals (e.g. Branco, 1994; Vagstad, 1995; Naegelen and Mougeot, 1998). Nevertheless, these works are static and usually assume that local suppliers are weak firms. Indeed, procurement is a repeated game, and current awarding policies may affect the future market structure of industries in which suppliers' efficiency is endogenously determined.

In this paper, we characterize the optimal dynamic procurement design when firms are symmetric with respect to their initial production cost, but learning-by-doing makes incumbent firms more efficient over time and some firms have synergies across markets. Empirical studies have documented that such positive synergies are prevalent in several industries. For instance, Hendricks and Porter (1988), De Silva et al. (2003, 2005) and De Silva (2005) find that previous information and past experience in drainage lease contracts and in road construction increase firms' efficiency in related activities, thereby affecting their bidding behavior in procurement auctions. Our dynamic environment allows us to account for the long-run impact of procurement discrimination on firms' efficiency and market structure.

To investigate the dynamic aspects of discrimination in procurement, we study a two-period model of procurement design in which two types of firms compete for public good provision: local and global firms. In each period, the public authority chooses the procurement mechanism that maximizes the social welfare net of the cost of public funds. Firms privately know their own cost for producing the public good in the correspondent period. Firms are symmetric with respect to their initial first-period cost distribution, and both firm types

[1] The U.S. Small Business Act, established on July 30, 1953, stipulates a "fair proportion" of government contracts and sales of surplus property to small business.

benefit from learning-by-doing, in the form of expected cost reduction over time, if they provide the public good in the previous period. Contrary to local firms, global firms may have access to learning-by-doing even when they are not the incumbent in the local market. Indeed, global firms may have synergy advantages and learning-by-doing may be transferable from external markets – the unique difference between local and global firms that we consider.

Due to learning-by-doing, local and global firms may have high or low expected production costs in the last period of the game. This potential asymmetry between firms, combined with the assumption that firms are privately informed about their cost, implies that the authority faces the well-known static trade-off between rent extraction and efficiency in the second period (see, e.g. Myerson, 1981; McAfee and McMillan, 1989). In order to induce truthful revelation of production cost, the public authority has to give an extra rent to firms. The effective cost of the provision by a firm is the virtual production cost: the sum of firm's actual cost plus the informational rent. When the authority knows that firms have asymmetric costs' distribution, it is optimal to bias the awarding rule in favor of the firm with the highest expected cost in order to reduce the informational rent of the firm with the lowest expected one. As a result, the public authority may not select the firm with the lowest cost (i.e. the most efficient one) if it has a too high informational rent.

In the first period, firms have symmetric costs' distribution. Therefore, there is no need to bias the procurement from the static trade-off perspective. However, biasing the procurement may still be optimal. Indeed, the authority faces a dynamic trade-off between low monetary transfer today and high monetary transfer tomorrow, which has not been addressed in previous studies. On one hand, a selection of a global firm with low cost in the first period implies low monetary transfer in this period. On the other hand, it implies high expected monetary transfer in the second period: the local firm, the global firm's opponent, without previous experience (learning-by-doing) certainly will have higher expected cost in the second period. In contrast, the global firm may still be a competitor with low expected cost in the second-period even if it is not the incumbent firm in the local market. These effects go in opposite directions. However, under certain conditions on the cost distribution, we find that it is optimal for the public authority to discriminate in favor of the local firm in the first period. This bias increases the chances of creating a pool of firms with low expected cost in the future, enhancing future competition and reducing expected transfer. Accordingly, a first-period bias is optimal even if part of the competitive advantage of an incumbent firm will be corrected by a bias in the second-period procurement. This implies that the local firm may be optimally selected, even though it has higher first-period production cost than the global one.

Our results are interesting for a variety of reasons. First, recent empirical works study the effect of discriminatory programs that favor potentially weak bidders (i.e. minority-owned firms and small businesses) in several industries. For instance, Marion (2007) and

Krasnokutskaya and Seim (2010) study the effect of small business bid subsidies in California highway procurement auctions, and Athey, Coey and Levin (2013) analyze set-asides of forest service timber auctions for small businesses in the U.S..[2] These studies find that discriminatory programs have negative effects on public budgeting, increasing procurement costs and reducing government revenue. In particular, the pool of efficient firms participating to the procurement contest seems to be determinant for procurement costs. Even though all these studies only take into account the instantaneous and short-run effects of those programs, they suggest that the long-run impact of discrimination on market structure and future competition are keys aspects and should be considered when evaluating those policies. Our paper provides a theoretical framework to understand the dynamic implications of discriminatory programs.

Second, in industries with learning-by-doing and synergies across markets, the use of a repeated symmetric mechanism rather than the optimal discriminatory mechanism characterized in this paper has important economic consequences. In particular, in a repeated first-price sealed-bid auction without discrimination, the public authority pays higher expected monetary transfer for good suppliers, and the global firms earn higher rents. Intuitively, global firms have lower expected production cost than local ones due to learning-by-doing and synergies across markets. With level-playing-field bidding, the latter would impose little competition pressure on the former, who could be get away with bidding relatively high. We present empirical evidence in accordance with those results, which we interpret as further evidence supporting the importance of designing optimal discriminatory policies (see Section 5.3).

In our basic model, the global firm does not incur costs to transfer learning-by-doing from external markets to a market where it is not an incumbent. Nevertheless, a global firm may have to make some technological adaptation in order to transfer external learning to the local market. In order to understand how a costly adaptation of external learning affects the optimal mechanism, we consider a modified version of our model in which the global firm makes a costly investment to adapt external learning to local conditions. Interestingly, in addition to making transferability of learning endogenous, costly technology adaption introduces a new ingredient in the problem faced by the public authority in the first period: the public authority would like to induce global firm's investment in technology adaptation as this reduces its expected transfers to the providers in the future. The public authority now faces a trade-off between favoring the local firm to foster future competition versus favoring the global firm to induce high technological adaptation. On one hand, the public authority would like to select the local firm with high probability in the first-period to enhance future competition. On the other hand, to induce global firm's investment in technology adaptation, the public authority has to select the global firm in the first-period with high probability. Putting those two opposing

[2] Rothkopf, Harstad and Fu (2003), and Hubbard and Paarsch (2009) numerically analyze the cost and benefits of bid-preference programs.

effects together, we can show that when technology adaption investment has limited impact on transferability of external learning, then the public authority favors the local firm in the first period. Otherwise, it prefers to favor the global one.

Related Literature. This paper is related to the literature on discrimination in procurement and auctions, started with Myerson (1981). Myerson shows that in asymmetric auctions where firms have different (ex-ante) levels of efficiency, the buyer may gain from discriminating in favor of a weak seller. McAfee and McMillan (1989) use this result to explain government's discriminatory policies in favor of domestic (weak) firms. Yet, Branco (1994), Vagstad (1995) and Naegelen and Mougeot (1998) show that the awarding rule amounts to subtracting from the local firm's cost a term. The sign of this term varies with comparative advantages, the social cost of public funds and the weight attached to the local profit. Other theoretical papers such as Demski, Sappington and Spiller (1987), Cabral and Greenstein (1990), and Rezende (2009), also provide economic rationales for discrimination in procurement.[3] Jehiel and Lamy (2015) show that when entry is endogenous, the revenue-maximizing equilibrium requires that there should be no discrimination with respect to entrants irrespective of their ex-ante characteristics. However, all these papers are static arguments. Some recent studies, as ours, look at the dynamic effects of bid preference. Branco (2002), for instance, shows that protection of inefficient firms may have perverse effects on incentives that lead firms to adopt more efficient technologies. Arve (2014) shows that favoring financially weak firms today may reduce the financially strong player's expected future gains, thereby increasing the government intertemporal payoff. Differently, Cisternas and Figueroa (2015) show that favoring the incumbent in the future induces more competition today. Our paper contributes to this literature by showing the implications of discrimination policies on market structure and future competition in industries where learning-by-doing makes incumbent firms more efficient over time.

Our paper also contributes to the literature on dynamic procurement/regulation design when learning-by-doing determines firm's efficiency. Baron and Besanko (1984) and Laffont and Tirole (1988) derive the optimal pricing/contracting policy of a two-period model of regulation in which incumbent's investment in learning reduces second-period production cost. Lewis and Yildirim (2002) and Osmundsen (2002) characterize the optimal dynamic regulation problem when firms learn from previous experience and production. In these previous works,

[3] An usual way to discriminate among firms, known as right of first refusal (ROFR), is giving to one of the preferred bidders the right to match the lowest bid that any of her rivals may submit. This right has been studied in Walker (1999), Burguet and Perry (2009), Bikhchandani, Lippman and Ryan (2005), Arozamena and Weinschelbaum (2006), Choi (2009) and Lee (2008). Deb and Pai (2015) show that any discriminatory goal can be implemented by a symmetric auction with a modified payment rules for the winning and losing bidders.

the regulator commits to its announcement of how it will use the information that he obtains along the procurements in future procurements. Nevertheless, commitment over long periods in regulatory relationships is unlikely in the real world since the public authority's decision is often discretionary and subject to political constraints. Accordingly, we characterize the optimal dynamic procurement mechanism with learning-by-doing without assuming that the authority has commitment power.

This paper is also related to the literature on the effects of potential synergies on bidding behavior. Krishna and Rosenthal (1997), for instance, show that in simultaneous second-price auctions, global firms who bid on multiple objects bid more aggressively than local firms who bid on single objects. Branco (1997) also finds similar results in sequential English auctions. Jeitschko and Wolfstetter (2002) find that in recurring first-price auctions, bidders who have previously won may experience potential synergies in subsequent auctions. Leufkens, Peeters and Vorsatz (2012) use laboratory experiments to compare the performance of first-price and second-price auctions when two stochastically equivalent objects are auctioned sequentially and the winner of the first auction receives a positive synergy in the second auction. All these papers look at the optimal bidding behavior of firms with synergies when the auction mechanism is exogenously fixed, whereas we characterize the optimal sequential procurement auction in industries in which firms have such synergies. Francetich (2015) also characterizes the optimal sequential revenue-maximizing auction when firms are ex-ante symmetric and the incumbent becomes more efficient than other firms in future auctions. Differently, in our model firms (local and global) have different synergies advantages. This allows us to drawn new insights on the dynamic aspects of discrimination in procurement auctions.

The remainder of the paper is organized as follows. Section 2 describes our model and defines the sequential mechanism design problem of the public authority. In order to characterize the optimal sequential mechanism, we solve the model by backward induction. Accordingly, Section 3 characterizes the optimal second-period procurement mechanism. The main results of the paper are presented in Section 4 where the optimal first-period mechanism is characterized. Section 5 discusses the limits of the results to an alternative modeling that considers costly transferability of learning-by-doing across markets. We also provide evidence suggesting the empirical relevance of the presence of learning-by-doing and global firm's transferability. Finally, in Section 6 we offer some concluding remarks. The proofs of the propositions and lemmas can be found in the Appendix.

2 The Model

We consider a city-economy consisting of consumers, a public authority, a local firm L and a global firm G. All agents are risk-neutral, have a discount factor equal to 1 and live for two periods.

2.1 Public Authority and Consumers

A benevolent public authority is responsible for choosing the public good supplier in the city. The public good is indivisible and must be provided at most by one firm per period. This assumption fits to most of the cases of local public services and local public goods like garbage collection, street repairing, fire departments, local public transportation, and potable water (see Levin and Tadelis, 2010). We assume that the authority has to select its public good provider at the beginning of each period. This assumption seems realistic in environments in which the authority cannot credibly commit to follow its initial contract over long periods.[4] At the end of each period, the public authority taxes consumers in order to pay for the public good.

There is a continuum of identical consumers in the city. For simplicity, we assume that the sum of all consumers' utility for the public good is S per period, and that S is sufficiently large such that the public good is always provided.

The social welfare W_t in period $t = \{1, 2\}$ is defined by

$$W_t = S + \alpha(U_{Lt} + U_{Gt}) - (1 + \lambda)(T_{Lt} + T_{Gt}), \tag{1}$$

where S is the gross consumer surplus generated by the public good, U_{it} is firm i's profit in period t, with $i = \{L, G\}$, and α is the welfare weight associated to the firms. T_{it} denotes the monetary transfer made by the authority to the firm i in period t, λ is the cost of public funds with $\lambda > 0$ and $\alpha < 1 + \lambda$. This last condition implies that transferring money to the firms is socially costly for the authority. The intertemporal social welfare is the sum of the social welfare in the two periods.

2.2 Firms

There are two firms in the economy: a local firm L and a global firm G. When providing the public good in period t, firm $i \in \{L, G\}$ incurs a production cost c_{it}.

[4] Laffont and Tirole (1993) present some political economy arguments which explain the existence of institutional constraints limiting the long-term contracts in public good provision. See also Ellman (2012) for a theory on the optimal length of contracts in concessions.

Distributions of Costs. At the beginning of each period, c_{it} is drawn from a distribution function $F_{it}(.)$ on $\Delta_{it} = [\underline{c_{it}}, \overline{c_{it}}]$, with p.d.f. $f_{it}(.)$. Firms privately learn their own production cost for the correspondent period and firms' production cost is not verifiable. We assume that $\frac{F_{it}(c)}{f_{it}(c)}$ is continuous and non decreasing in c (see Myerson, 1981).

In the first period, firms' production costs are independently drawn from the same *weak* distribution function $F_w(.)$ on $\Delta_w = [\underline{c_w}, \overline{c_w}]$, with p.d.f. $f_w(.)$.

We assume that firms gain proficiency through repetition of an activity, i.e. learning-by-doing. Following Fudenberg and Tirole (1983), an incumbent firm which produces the public good in the first period will be granted an expected reduction in its second-period production cost. Hence, incumbent firms become more efficient over time when providing the public good, whereas new entrants do not. Incumbents are likely to have significant cost advantages relative to entrants for a number of reasons: entrants may face higher uncertainty in the development of production, since they lack experience, and may also have less access to information than incumbents regarding the pricing and cost of various production components. Empirical studies have found that incumbents' bidding behavior is consistent with this assumption. For instance, De Silva (2005) and De Silva et al. (2005) document that incumbent firms tend to bid less than entrants in auctions for road construction contracts, which suggests that past experience and previous works may reduce future production cost in related activities.

Formally, we assume that if firm i does not produce the good in the first period, it will have its second-period production cost c_{i2} drawn from the *weak* distribution function $F_w(.)$. On the contrary, when firm i provides the public good in the first period, its second-period production cost c_{i2} will be drawn from a *strong* distribution function $F_s(.)$ on $\Delta_s = [\underline{c_s}, \overline{c_s}]$, with p.d.f. $f_s(.)$. We assume that $F_s(c)$ conditionally stochastic dominates $F_w(c)$ for all $c \in (\underline{c_s}, \overline{c_w})$. The conditional stochastic dominance assumption implies: (i) first-order stochastic dominance, i.e. $F_s(c) > F_w(c)$; (ii) hazard-rate dominance, i.e. $\frac{F_s(c)}{f_s(c)} > \frac{F_w(c)}{f_w(c)}$; (iii) downward shifting in the boundaries of the distribution function: $\underline{c}_s \leq \underline{c}_w$ and $\overline{c}_s \leq \overline{c}_w$.[5]

Condition (i) states that the incumbent firm has a lower expected cost than an entrant (i.e. $E_s[c] < E_w[c]$), and condition (ii) states that the entrant firm has lower unit profit than the incumbent one. With some abuse of notation, we call a *strong* (respectively *weak*) firm, a firm that has its cost drawn from a *strong* (respectively *weak*) distribution function $F_s(.)$ (respectively $F_w(.)$).

Local versus Global Firms. So far we have not made any distinction between local and global firms. In our model, we assume that there is only one difference between them: the local firm can produce the public good only in the local city, whereas the global firm can

[5]Such distinction between firms based on conditional stochastic dominance was first introduced by Maskin and Riley (2000).

produce the good in several cities at the same time, i.e. in the local city and also elsewhere.

Such asymmetry between local and global firms is prevalent in several countries. In France, for instance, there are typically two kinds of competitors for local public services: public and private firms. The public firms are usually operated by civil servants of the city and only compete and provide the public services within the city, i.e. local market. In contrast, private firms such as Veolia or Lyonnaise Des Eaux compete and provide public services across multiple cities and markets (see, e.g., Desrieux, Chong and Saussier, 2013). In Brazil, there are typically three kind of competitors for distribution of drinking water and sewage treatment: local public, state and private firms. As in France, local public firms only compete and provide services in their home city, whereas state and private firms compete and provide such services in many cities (see, e.g., Oliveira and Scazufca, 2009). Alternatively, we can also interpret the local firm as a small one, and the global firm as a big one.

The global firm's ability to compete and serve several markets may give it many advantages over local firms.[6] In this paper, we present transferability of learning as a new advantage. Providing the public good in many cities at the same time allows the global firm to transfer technology from cities where it is incumbent and, therefore, it has gained learning-by-doing, to cities where it is not. Because the global firm can transfer learning inside the firm, the global firm may be able to reduce expected costs, even if it is a new entrant to the market. In contrast, the local firm has cost reduction only if it is the incumbent.

Empirical studies provide evidence consistent with the assumptions of transferability of learning among related activities in different markets. For instance, Gandal (1997) find that the existence of economies of scope in infrastructure development and service maintenance in cable television licenses increases the firms' value for neighboring franchises. Ausubel et al. (1997) show that there are geographic synergies associated with winning multiple adjacent licenses in spectrum license auctions in the United States. McMillan (1994), discussing the potential efficiencies from license aggregation in the FCC spectrum auctions, provides evidence that economies of scale and scope in adjacent spectrum licenses are also prevalent in the U.S.. In addition, De Silva (2005) finds that past winners of road construction contracts make lower bids in auctions for related contracts in a different geographic area, and interprets this as evidence of spacial synergies in the industry.

In order to model transferability of learning, we assume that there exist two possible states of the world in the end of the first period. With exogenous probability $\theta \in (0,1)$ the global firm is the provider of the public good (incumbent) elsewhere, therefore it can transfer learning to the local city. Consequently, it expects to have c_{G2} distributed according to the

[6] Firms that serve several markets and supply related contracts can avoid duplication of costs, and share recourses and expertise among various projects. Tirole (1988), for instance, discusses the economies of scope and scale in multi-product and multi-market firms.

strong distribution function $F_s(.)$. With probability $1 - \theta$, the global firm does not provide the public good elsewhere. Hence, it expects to have c_{G2} distributed according to the *weak* distribution function $F_w(.)$, unless it is the incumbent in the local city. We assume that the realization of global firm's transferability is observable by all agents.[7]

The ability to transfer learning among cities makes the global firm more competitive over time in expectation than the local one. Even if local and global firms are symmetric with respect to the first-period cost distribution, i.e. both firms' first-period costs are drawn from the weak distribution, global firm's transferability makes the firms different. The higher the probability θ, the higher the probability that the global firm transfers learning from external markets to the local city. The parameter θ captures global firm's ability to transfer learning between different cities.

In the second period, depending on the selection of the first-period provider and the realization of the transferability, there exist four possible contingencies when firms compete for the public good provision. To reduce notation, all possible contingencies are summarized by a state variable X with three possible states:

- **State $X = 1$: Incumbent Local Firm and Global Firm without Transferability.** In the first period, the local firm is the public good provider in the city and the global firm is not incumbent elsewhere. Then, in the second period, the local firm's cost c_{L2} will be drawn from the strong distribution function $F_s(.)$, and the global private firm's cost c_{G2} will be drawn from the weak distribution function $F_w(.)$.

- **State $X = 2$: Incumbent Local Firm and Global Firm with Transferability.** In the first period, the local firm is the public good supplier in the city and the global firm is incumbent elsewhere. So, in the second period, firms' cost, c_{L2} and c_{G2}, will be drawn from the same strong distribution function $F_s(.)$.

- **State $X = 3$: Incumbent Global Firm.** In the first period, the global firm is the public good provider in the city and also elsewhere; or the global firm is the public good provider in the city but not elsewhere. These two contingencies are equivalent with respect to the distribution of firms' second-period costs. Then, in the second period, the global firm's cost c_{G2} will be drawn from the strong distribution function $F_s(.)$, and local firm's cost c_{L2} will be drawn from the weak distribution function $F_w(.)$.

[7] In Section 5 we consider a modified version of our model in which the probability θ is endogenous and transferability of learning from external markets is costly.

2.3 Sequential Mechanism Design

At the beginning of each period, the authority has to design a procurement mechanism to select and to pay firms for the public good provision, so as to maximize its expected social welfare subject to the constraints imposed by its lack of knowledge about firms' costs. This sequential mechanism problem defines a dynamic game with incomplete information between the public authority and the firms. As we have assumed that firms' production costs are independently drawn over time, we can apply the Revelation Principle sequentially. We can restrict our attention to simple direct-revelation dynamic mechanisms because, under sequential draw and serial independence of the production costs, firms cannot commit to second-period messages beforehand. Therefore, first-period allocation, which is a common knowledge, conveys all information about firms' second-period production cost.

By the Revelation Principle (see Myerson, 1981), for any optimal sequential mechanism there is an equivalent direct sequential mechanism in which firms reveals their production cost in each period, and the project is awarded and payments are made according to the costs revealed.

The *optimal sequential direct mechanism* is defined as $\mathcal{M}_1 = \{\Delta_1, p_1(c_1), T_1(c_1)\}$, the first-period direct mechanism, and $\mathcal{M}_2(X) = \{\Delta_2(X), p_2(c_2, X), T_2(c_2, X)\}$, the second-period direct mechanism in each possible contingency X, where $\Delta_t = (\Delta_{Lt}, \Delta_{Gt})$ is the set of possible costs for each firm in period t; $c_t = (c_{Lt}, c_{Gt})$ is the vector of true costs; $p_t(c_t) = (p_{Lt}(c_t), p_{Gt}(c_t))$ is the vector of the probability of awarding the project to each firm; $T_t = (T_{Lt}, T_{Gt})$ is the vector of expected payment to firms.[8]

The direct mechanism $\mathcal{M}_t$ in period t maximizes the social welfare, subject to three constraints: individual rationality constraints, incentive compatibility constraints, and possibility constraints. The individual rationality constraints guarantee that the break even condition of firms is satisfied in each period. The incentive compatibility constraints impose that firms have incentive to reveal truthfully their production cost in each period. The possibility constraints ensure that in each period a firm is granted with the public good provision with probability lower or equal than one, and that the sum of these probabilities is equal to 1.

2.4 Timing

The timing of the game is as follows:

Period 1 (i) Nature draws firms' production cost for the first period from $F_w(.)$.

[8] There is no loss of generality in assuming that the second-period mechanism depends only on the state variable and firms' second-period revealed cost. It occurs because the only important variables for the authority to find the optimal mechanism in period 2 are the firms' type and firms' second-period cost. Such information is summarized in variables X and $c_2 = (c_{L2}, c_{G2})$. Firms' first-period revealed cost does not provide any additional information to the one conveyed by those variables.

(ii) Each firm privately learns its own first-period cost.

(iii) The authority offers the first-period procurement mechanism $\mathcal{M}_1$, which defines an allocation and payment rule.

(iv) Firms report their costs. The firms decide whether or not to participate.

(v) The authority chooses the provider and transfers are made according to $\mathcal{M}_1$.

Period 2 (vi) Nature draws the global firm's transferability: with probability θ the global firm can transfer the learning-by-doing. The realization of the transferability is observed by all agents.

(vii) Nature draws firms' production cost for the second period from the distribution corresponding to the realization of transferability and first-period selection.

(viii) Each firm privately learns its own second-period cost.

(ix) The authority offers the second-period procurement mechanism $\mathcal{M}_2$.

(x) Firms report their costs. The firms decide whether or not to participate.

(xi) The authority chooses the provider and transfers are made according to $\mathcal{M}_2$.

In order to characterize the optimal sequential direct mechanism, we solve the model by backward induction. We first find the optimal second-period mechanism in each possible contingency. Then, we turn to the characterization of the optimal first-period mechanism, which takes into account the optimal mechanism that will be chosen in period 2.

3 Second-period Procurement

The expected profit of firm i in period 2 in state X is denoted by

$$U_{i2}(c_{i2}, X) = E_{c_{-i2}}[T_{i2}(c_2, X) - c_{i2}p_{i2}(c_2, X)|X], \tag{2}$$

where $T_{i2}(c_2, X)$ is the monetary transfer that firm i receives for the public good provision in state X, and $c_{i2}p_{i2}(c_2, X)$ is its expected production cost, with $p_{i2}(c_2, X)$ the firm i's probability of being the public good provider in state X.

At the beginning of period 2, conditional on the realized state X, the public authority's objective function is:

$$W_2(X) = \int_{\Delta_2(X)} \Big\{ \big(\sum_i p_{i2}(c_2, X) \big) S + \alpha \sum_i \big(T_{i2}(c_2, X) - c_{i2}p_{i2}(c_2, X) \big)$$

$$-(1+\lambda)\Big(\sum_i T_{i2}(c_2,X)\Big)\Big\}f_2(c_2|X)dc_2, \tag{3}$$

with $\Delta_2(X) = \Delta_{i2}(X) \times \Delta_{-i2}(X)$, and $f_2(c_2|X) = f_{i2}(c_{i2}|X)f_{-i2}(c_{-i2}|X)$.

The public authority designs $\mathcal{M}_2(X)$ that solves

$$\max_{p_2(c_2,X),T_2(c_2,X)} W_2(X) \qquad \text{subject to} \tag{P_I}$$

1. individual rationality constraints in state X:

$$U_{i2}(c_{i2},X) \geq 0, \forall i, \forall c_{i2} \in \Delta_{i2}(X); \tag{$IR_2(X)$}$$

2. incentive compatibility constraints in state X:

$$U_{i2}(c_{i2},X) = U_{i2}(c_{i2},c_{i2},X) \geq U_{i2}(\hat{c}_{i2},c_{i2},X),\ \forall i, \forall c_{i2}, \hat{c}_{i2} \in \Delta_{i2}(X), \tag{$IC_2(X)$}$$

with $U_{i2}(\hat{c}_{i2},c_{i2},X) = E_{c_{-i2}}[T_{i2}(\hat{c}_{i2},c_{-i2},X) - c_{i2}p_{i2}(\hat{c}_{i2},c_{-i2},X)|X]$;

3. possibility constraints in state X:

$$p_{i2}(c_2,X) \geq 0, \forall i, \text{ and } \sum_i p_{i2}(c_2,X) = 1, \forall c_2 \in \Delta_2(X). \tag{$PC_2(X)$}$$

Standard treatment of this problem implies that the public authority's problem P_I can be rewritten as:[9]

$$\max_{p_2(c_2,X)} \quad \int_{\Delta_2(X)} \left\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{L2}|X)} \right] p_{L2}(c_2, X) \right.$$
$$\left. + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} \right] p_{G2}(c_2, X) \right\} f_2(c_2|X)dc_2$$
$$-(1+\lambda-\alpha)\left\{ U_{L2}(\overline{c_{L2}}(X), X) + U_{G2}(\overline{c_{G2}}(X), X) \right\} \tag{6}$$

subject to

$$U_{i2}(\overline{c_{i2}}(X), X) \geq 0, \forall i;$$
$$\frac{dQ_{i2}(c_{i2}, X)}{dc_{i2}} \leq 0, \forall i;$$
$$p_{i2}(c_2, X) \geq 0, \forall c_2 \in \Delta_2(X), \forall i, \text{ and } \sum_i p_{i2}(c_2, X) = 1.$$

The optimal mechanism is the solution of the pointwise maximization problem above. The following proposition characterizes the optimal mechanism.[10]

Proposition 1 *The optimal second-period mechanism in state X satisfies:*

(i) $U_{i2}(\overline{c_{i2}}(X), X) = 0, \forall i;$

(ii) $p_{L2}(c_2, X) = 1$ *and* $p_{G2}(c_2, X) = 0$ *if*

$$\Phi_{L2}(c_{L2}, X) \leq \Phi_{G2}(c_{G2}, X), \tag{7}$$

[9]We apply the Envelope Theorem to firms' maximization problem in $(IC_2(X))$ with respect to $\hat{c}_{i2}$ which yields

$$\frac{dU_{i2}(c_{i2}, X)}{dc_{i2}} = -E_{c_{-i2}}[p_{i2}(c_{i2}, c_{-i2}, X)|X] = -Q_{i2}(c_{i2}, X). \tag{4}$$

Equation (4) is a local incentive condition. It is a necessary and sufficient condition if the following condition holds:

$$\frac{dQ_{i2}(c_{i2}, X)}{dc_{i2}} \leq 0.$$

From equation (4), $U_{i2}(c_{i2}, X)$ is strictly decreasing in c_{i2}. So the individual rationality constraint $(IR_2(X))$ is satisfied if $U_{i2}(\overline{c_{i2}}(X), X) \geq 0$. Integrating (4), we have that

$$U_{i2}(c_{i2}, X) = U_{i2}(\overline{c_{i2}}(X), X) + \int_{c_{i2}}^{\overline{c_{i2}}(X)} Q_{i2}(s_{i2}, X)ds_{i2}. \tag{5}$$

[10]The proof of Proposition 1 is omitted. This proposition is similar to the results presented in Myerson (1981), McAfee and McMillan (1989), and Naegelen and Mougeot (1998).

where

$$\Phi_{i2}(c_{i2}, X) = (1+\lambda)c_{i2} + (1+\lambda-\alpha)\frac{F_{i2}(c_{i2}|X)}{f_{i2}(c_{i2}|X)}; \tag{8}$$

otherwise $p_{L2}(c_2, X) = 0$ *and* $p_{G2}(c_2, X) = 1$.

Equation (7) shows that the public good provision is awarded to the firm with the lowest virtual production cost rather than to the one with lowest production cost c_{i2}. It occurs because the public authority when selecting the public good provider faces a trade-off between efficiency and rent extraction. In order to induce truthful revelation of production cost, the public authority has to give an extra rent to firms (i.e. informational rent) which is proportional to the ratio $\frac{F_{i2}(c_{i2}|X)}{f_{i2}(c_{i2}|X)}$. The effective cost of the provision by a firm is the virtual production cost described in equation (8): the sum of firm's actual cost plus the informational rent. As a result, the public authority may not select the firm with the lowest cost (i.e. the most efficient one) if its informational rent is too high.

Optimal Second-period Discrimination Policy. In order to characterize the second-period optimal discrimination policy, as in Naegelen and Mougeot (1998), we rewrite equation (7) as

$$c_{L2} \leq c_{G2} + \frac{(1+\lambda-\alpha)}{(1+\lambda)}\left[\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} - \frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{L2}|X)}\right]. \tag{9}$$

The last term on the right hand side in equation (9) is the optimal bias. The public authority adds (respectively subtracts) an "extra cost" from the local firm cost c_{L2} when $\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} - \frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{l2}|X)}$ is positive (respectively negative) in order to optimally make its selection decision. The optimal discrimination policy, if any, depends on firms' cost distribution in each state.

- **State $X = 1$.** Firms are not symmetric. Local firm's second-period cost is drawn from the strong distribution function $F_s(.)$, whereas the global has its second-period cost drawn from the weak distribution function $F_w(.)$. Replacing these functions in equation (9), we obtain that the optimal allocation rule is to select the local firm to be the public good provider with probability one if

  $$c_{L2} \leq c_{G2} + \frac{(1+\lambda-\alpha)}{(1+\lambda)}\left[\frac{F_w(c_{G2})}{f_w(c_{G2})} - \frac{F_s(c_{L2})}{f_s(c_{l2})}\right]. \tag{10}$$

  As $\frac{F_s(c)}{f_s(c)} > \frac{F_w(c)}{f_w(c)}$, the local firm has higher informational rent than the global one, then the public authority subtracts an "extra cost" from the global firm's cost to make the selection. As a result, the local firm may not be selected with probability one even though it has the lowest production cost. Therefore, the public authority discriminates in favor of the global firm rather than selecting the most efficient firm, i.e. the local one.

- **State** $X = 2$**.** Firms are symmetric. The local and global firm have their costs drawn from the strong distribution function $F_s(.)$, so they have the same informational rent. Due to this symmetry, the public authority does not need to favor one of the firms. The public good provision is awarded to the firm with the lowest cost.

- **State** $X = 3$**.** This state is symmetric to state $X = 1$: the local firm's cost is drawn from a weak distribution and the global from a strong distribution. Therefore, in state $X = 3$ the public authority adds an "extra cost" to the global firm's cost. As a result, the global firm may not be selected with probability one even though it has the lowest production cost.

The optimal second-period discrimination policy is such that the public authority may select a firm with higher actual cost than its opponent when firms are not symmetric with respect to their cost distribution. This happens in states $X = 1$ and $X = 3$. When firms are symmetric, i.e. $X = 2$, the public authority awards the good provision to the most efficient firm.

4 First-period Procurement

We turn to the characterization of the first-period optimal mechanism. In order to characterize firms' first-period strategy and public authority's problem in period 1, we first compute the continuation payoffs of the firms and the public authority.

4.1 Continuation payoffs

The continuation payoffs are computed at the end of the first period, after first-period public good provision was awarded and before Nature draws the transferability. In period 1, neither the authority nor the firms know firms' second-period costs and global firm's transferability. However, as the public authority will optimally select and pay firms in period 2 according to the second-period mechanism described in Proposition 1, we can compute firms' expected equilibrium payoff and public authority's expected equilibrium payoff at the beginning of period 2.

Firms' continuation payoff. We denote by $U_i^C(p_{L1}, p_{G1})$ the continuation payoff function of firm i. Let $\tilde{U} \equiv \int_{\underline{c}_s}^{\bar{c}_s}(1 - F_s(c))F_s(c)dc$ be the second-period expected payoff of a strong firm when it faces a strong opponent. Similarly, we define $\overline{U} \equiv \int_{\underline{c}_s}^{\overline{c}_s}(1 - F_w(\Phi_w^{-1}(\Phi_s(c))))F_s(c)dc$ (respectively $\underline{U} \equiv \int_{\underline{c}_w}^{\overline{c}_w}(1 - F_s(\Phi_s^{-1}(\Phi_w(c))))F_w(c)dc$) as the second-period expected payoff of a strong (resp. weak) firm when it faces a weak (resp. strong) opponent, in which $\Phi_s(c) \equiv (1+\lambda)c + (1+\lambda-\alpha)\frac{F_s(c)}{f_s(c)}$ and $\Phi_w(c) \equiv (1+\lambda)c + (1+\lambda-\alpha)\frac{F_w(c)}{f_w(c)}$. The functions $\Phi_s(c)$ and $\Phi_w(c)$ are the sum of firm's actual cost plus the informational rent when its production cost is drawn from a strong and a weak cost distribution, respectively.[11] Notice that these values are not indexes by i as they are identical for the two types of firms.

Lemma 1 *The continuation payoffs of the firms are such that*

(i) if the local firm is awarded the first-period public good provision, i.e. $p_{L1} = 1$ *and* $p_{G1} = 0$*, then* $U_L^C(1,0) = \theta\tilde{U} + (1-\theta)\overline{U}$ *and* $U_G^C(1,0) = \theta\tilde{U} + (1-\theta)\underline{U}$*;*

(ii) if the global firm is awarded the first-period public good provision, i.e. $p_{L1} = 0$ *and* $p_{G1} = 1$*, then* $U_L^C(0,1) = \underline{U}$ *and* $U_G^C(0,1) = \overline{U}$*.*

Once we have characterized firms' continuation payoff, we can derive firm's expected payoff in period 1. The expected payoff of firm i is the sum of the first-period profit and the continuation payoff. Hence,

$$U_i(c_{i1}) = E_{c_{-i1}}[T_{i1}(c_1) - c_{i1}p_{i1}(c_1) + U_i^C(p_{L1}(c_1), p_{G1}(c_1))],$$

where $T_{i1}(c_1)$ and $p_{i1}(c_1)$ are, respectively, the payment and allocation rules in the first-period mechanism.

Public Authority's continuation payoff. We denote by $W^C(p_{L1}, p_{G1})$ and $S^C(p_{L1}, p_{G1})$, respectively, the public authority's continuation payoff and expected net continuation consumers' surplus (consumers surplus minus expected payment to firms). We define by

$$\overline{S} \equiv S - 2(1+\lambda)E_s\big[E_s[c \cdot 1\{c \le c'\}|c']\big], \tag{11}$$

$$\underline{S} \equiv S - (1+\lambda)\Big[E_s\big[E_w[c'' \cdot 1\{c'' \le \Phi_w^{-1}(\Phi_s(c))\}|c]\big] + E_w\big[E_s[c \cdot 1\{c \le \Phi_s^{-1}(\Phi_w(c''))\}|c'']\big]\Big], \tag{12}$$

$$\overline{W} \equiv \overline{S} - (1+\lambda-\alpha)2\tilde{U}, \tag{13}$$

$$\underline{W} \equiv \underline{S} - (1+\lambda-\alpha)(\underline{U} + \overline{U}), \tag{14}$$

where $1\{\cdot\}$ is an indicator function, c and c' are distributed according to $F_c(.)$, and c'' according to $F_w(.)$.

[11] The formal definitions of the payoffs are relegated to the Appendix.

The term $\overline{S}$ (resp. $\underline{\mathrm{S}}$) represents the net expected consumers' surplus when two strong (resp. one strong and one weak) firms are competing in the second period. Similarly, $\overline{W}$ (resp. $\underline{\mathrm{W}}$) represents the expected welfare derived by the authority when two strong (resp. one strong and one weak) firms are competing in the second period.[12]

The following Lemma characterizes the public authority's continuation payoff.

Lemma 2 *The public authority's continuation payoff is such that*

(i) if the local firm is awarded the first-period public good provision, i.e. $p_{L1} = 1$ *and* $p_{G1} = 0$*, then*

$$W^C(1,0) = \theta\overline{W} + (1-\theta)\underline{W} \qquad \text{and} \qquad S^C(1,0) = \theta\overline{S} + (1-\theta)\underline{S}; \tag{15}$$

(ii) if the global firm is awarded the first-period public good provision, i.e. $p_{L1} = 0$ *and* $p_{G1} = 1$*, then*

$$W^C(0,1) = \underline{W} \qquad \text{and} \qquad S^C(0,1) = \underline{S}. \tag{16}$$

When the local firm is awarded with the first-period public good provision, then public authority's continuation payoff and the expected net continuation consumers surplus are given by (15). Indeed, suppose that the local firm is selected in period 1 (Lemma 2 (i)). In this case, with probability θ, there will be two strong firms (i.e. incumbent local and entrant global with transferability) competing for the public good provision in period 2. Consequently, the public authority and consumers will derive, respectively, high continuation payoff $\overline{W}$ and high continuation consumers net surplus $\overline{S}$. With probability $1-\theta$, there will be one strong firm (incumbent local) and one weak firm (entrant global without transferability) competing for public good provision in period 2. The public authority and consumers will derive, respectively, low continuation payoff $\underline{W}$ and low continuation consumers net surplus $\underline{S}$.

The following proposition compares the public authority's continuation payoff $W^C(.)$ and expected net continuation surplus $S^C(.)$ in the two cases described in Lemma 2.

Proposition 2 *The public authority's continuation payoff and expected net consumers surplus functions are such that:*

(i) $\overline{W} > \underline{W}$*, which implies that* $W^C(1,0) > W^C(0,1)$*;*

[12]The formal definitions of public authority's continuation payoff and expected net continuation consumers' surplus are in the Appendix.

(ii) $\overline{S} \geq \underline{S}$ *if and only if*

$$\int_{\underline{c}_s}^{\bar{c}_s} c(1-F_s(c))f_s(c)dc \;\; \leq \;\; \frac{1}{2}\Bigg\{ \int_{\underline{c}_s}^{\bar{c}_s} \Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))} \widetilde{c} f_w(\widetilde{c}) d\widetilde{c} \Big] f_s(c)dc + $$
$$+ \int_{\underline{c}_w}^{\bar{c}_w} \Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))} \widetilde{c} f_s(\widetilde{c}) d\widetilde{c} \Big] f_w(c)dc \Bigg\}, \tag{17}$$

which implies that $S^C(1,0) > S^C(0,1)$.

When (17) holds, Proposition 2 shows that the expected net continuation consumers' surplus is strictly higher when the first-period provider is the local firm.

The intuition behind Proposition 2 is the following. When the local firm is selected in period 1 (Lemma 2 (i)), with probability θ there will be a fierce competition between two strong (local and global) firms and this leads to *low* expected transfers and *high* expected social welfare in the second period. With probability $1-\theta$, there will be mild competition between one strong (local) firm and one weak (global) firm and this leads to *high* expected transfer and *low* social welfare in the second period. Yet, when the global firm is selected in period 1 (Lemma 2 (ii)), there cannot be fierce competition in the second period. The global firm will always be the unique strong firm.

This result captures the fact that the authority has no chance to have two strong firms competing for its procurement when the incumbent is the global firm. Interestingly, this shows that the discrimination in favor of the weak firm introduced in the second period is not enough, from an ex ante perspective, to correct for the advantage due to the transferability enjoyed by the global firm over the local one.

Section 5.2 includes numerical results in which we show that equation (17) holds for classical families of distributions that satisfy the assumption that $F_s(c)$ conditionally stochastic dominates $F_w(c)$, described in Section 2.2.[13]

Having characterized the public authority's continuation payoff, we can derive its expected intertemporal social welfare. It is the sum of the first-period social welfare

$$W_1(p_1(c_1), T_1(c_1)) = \sum_i p_{i1}(c_1)S + \alpha \sum_i \big(T_{i1}(c_1) - c_{i1}p_{i1}(c_1)\big) - (1+\lambda)\sum_i T_{i1},$$

and its continuation payoff, defined in Lemma 2. So, the intertemporal public authority's

[13]If equation (17) does not hold, then the expected net continuation consumers' surplus is strictly higher when the first-period provider is the global firm (i.e., $\overline{S} < \underline{S}$).

payoff can be written as:

$$W=\int_{\Delta_1}\Big\{W_1(p_1(c_1),T_1(c_1))+p_{L1}(c_1)[\theta\overline{W}+(1-\theta)\underline{W}]+(1-p_{L1}(c_1))\underline{W}\Big\}f_1(c_1)dc,$$

where $f_1(c_1)=f_w(c_{L1})f_w(c_{G1})$. The vector-functions $T_1(.)=(T_{L1}(.),T_{G1}(.))$ and $p_1(.)=(p_{L1}(.),p_{G1}(.))$ are respectively the first-period expected payments and allocation rule.

Notice that the mechanism chosen in period 1 affects the first-period social welfare and also the public authority's continuation payoff. These effects associated to the choice of the first-period mechanism are analyzed in the next section.

4.2 Optimal first-period mechanism

The authority designs the first-period direct mechanism $\mathcal{M}_1$ that solves the following program:

$$\max_{p_1(c_1),T_1(c_1)} W \qquad \text{subject to} \tag{P_{II}}$$

1. individual rationality constraints:

$$U_i(c_{i1})\geq 0,\forall i,\forall c_{i1}\in\Delta_{i1}; \tag{IR_1}$$

2. incentive compatibility constraints:

$$U_{i1}(c_{i1})=U_{i1}(c_{i1},c_{i1})\geq U_{i1}(\hat{c}_{i1},c_{i1}),\ \forall i,\forall c_{i1},\hat{c}_{i1}\in\Delta_{i1}, \tag{IC_1}$$

where $U_{i1}(\hat{c}_{i1},c_{i1})=E_{c_{-i1}}[T_{i1}(\hat{c}_{i1},c_{-i1})-c_{i1}p_{i1}(\hat{c}_{i1},c_{-i1})+U_i^C(p_{L1}(\hat{c}_{i1},c_{-i1}),p_{G1}(\hat{c}_{i1},c_{-i1}))]$;

3. possibility constraints in period 1:

$$p_{i1}(c_1)\geq 0,\ \forall i,\forall c_1\in\Delta_1,\text{and}\ \sum_i p_{i1}(c_1)=1, \tag{PC_1}$$

where $\Delta_{i1}=[\underline{c_w},\overline{c_w}]$ and $\Delta_1=[\underline{c_w},\overline{c_w}]\times[\underline{c_w},\overline{c_w}]$.

Standard treatment of this problem implies that the public authority's problem P_{II} can be written as:[14]

$$\max_{p_{L1}(c_1),p_{G1}(c_1)} \quad \int_{\Delta_1}\left\{\left[S+\left[\theta\overline{S}+(1-\theta)\underline{S}\right]-(1+\lambda)c_{L1}-(1+\lambda-\alpha)\frac{F_w(c_{L1})}{f_w(c_{L1})}\right]p_{L1}(c_1)\right.$$
$$\left.+\left[S+\underline{S}-(1+\lambda)c_{G1}-(1+\lambda-\alpha)\frac{F_w(c_{G1})}{f_w(c_{G1})}\right]p_{G1}(c_1)\right\}f_1(c_1)dc_1$$
$$-(1+\lambda-\alpha)\left\{U_{L1}(\overline{c_w})+U_{G1}(\overline{c_w})\right\} \tag{19}$$

subject to

$$U_{i1}(\overline{c_w})\geq 0, \forall i;$$
$$\frac{dQ_{i1}(c_{i1})}{dc_{i1}}\leq 0, \forall i;$$
$$p_{i1}(c_1)\geq 0, \forall c_1\in\Delta_1, \forall i, \text{ and } \sum_i p_{i1}(c_1)=1.$$

The following proposition characterizes the first-period optimal mechanism.

Proposition 3 *The optimal first-period mechanism satisfies:*

(i) $U_{i1}(\overline{c_w})=0, \forall i$*;*

(ii) $p_{L1}(c_1)=1$ *and* $p_{G1}(c_1)=0$ *if*

$$\theta\overline{S}+(1-\theta)\underline{S}-\Phi_1(c_{L1})\geq\underline{S}-\Phi_1(c_{G1}), \tag{20}$$

where $\Phi_1(c_{i1})=(1+\lambda)c_{i1}+(1+\lambda-\alpha)\frac{F_w(c_{i1})}{f_w(c_{i1})}$ *is firm i's first-period virtual cost; otherwise* $p_{L1}(c_1)=0$ *and* $p_{G1}(c_1)=1$*.*

From equation (20), the public authority awards the first-period public good provision to the firm with the highest net expected continuation consumers surplus $S^C(.)$ minus first-period virtual cost $\Phi_1(c_{i1})$. Note that this rule is different from the second-period optimal

[14] We apply the Envelope Theorem applied to firms' maximization problem in (IC_1) with respect to $\hat{c}_{i1}$ and yields

$$\frac{dU_i(c_{i1})}{dc_{i1}}=-E_{c_{-i1}}[p_{i1}(c_{i1},c_{-i1})]=-Q_{i1}(c_{i1}). \tag{18}$$

As in P_I, equation (18) is a local incentive condition and it is a necessary and sufficient when $Q_{i1}(c_{i1})$ is non increasing in c_{i1}. From equation (18), $U_{i1}(c_{i1})$ is strictly decreasing in c_{i1}. So, the individual rationality constraint (IR_1) is satisfied if $U_{i1}(\overline{c_w})\geq 0$. Integrating (18), we have that

$$U_{i1}(c_{i1})=U_{i1}(\overline{c_w})+\int_{c_{i1}}^{\overline{c_w}}Q_{i1}(s_{i1})ds_{i1}.$$

decision described Proposition 1, in which the authority only looks at firms' virtual cost. We can rewrite equation (20) as

$$\theta(\overline{S} - \underline{S}) + \Phi_1(c_{G1}) \geq \Phi_1(c_{L1}),$$

where $\theta(\overline{S} - \underline{S})$ represents the optimal bias.

As in the second-period mechanism, the authority needs to give extra rents to the firms in order to induce truthful revelation of costs. However, in contrast to the second period, firms have the same virtual cost as their costs' distributions are identical, i.e. both firms' costs are drawn from the weak distribution: the rents for both firms are proportional to the ratio $\frac{F_w(c)}{f_w(c)}$. So, there would be no reason to favor any firm if there were no dynamic effects.

However, if $\tilde{U}$ the second-period expected payoff of a strong firm when it faces a strong opponent is sufficiently high, then the authority in the first period faces a dynamic trade-off between low monetary transfer today and high monetary transfer tomorrow, which is not present in the second-period decision. Such trade-off exists because, from Proposition 2, the authority's continuation payoff is strictly higher under local firm's provision in the first period: $\theta(\overline{S} - \underline{S}) > 0$. So, on the one hand, a selection of a global firm with low cost in the first period implies low monetary transfer in this period. On the other hand, it implies high expected monetary transfer in the second period. These effects go in opposite directions. However, we are able to show that it can be optimal for the public authority to discriminate in favor of the local firm in the first-period. That means that the local firm may be optimally selected, even though it has higher first-period production cost than the global one.

Proposition 4 *Suppose that equation (17) holds. The optimal discrimination policy in the first-period procurement mechanism is such that for any profile of revealed costs* (c_{L1}, c_{G1}) *there exists* $\overline{c}_{L1} > c_{G1}$ *such that the local firm is selected to be the public good provider with probability one if* $c_{L1} \leq \overline{c}_{L1}$*; otherwise the global firm is selected.*

By Proposition 4, the public authority selects a local firm with higher actual first-period cost than the global one when $c_{L1} \in [c_{G1}, \overline{c}_{L1}]$. The driving force behind this result is the following: the global firm enjoys a competitive advantage by being able to transfer learning-by-doing across markets. The bias of the second period mechanism in Proposition 1 reduces part of the rent generated by a competition between a weak versus a strong firm but is not able to reach the expected welfare achieved when two strong firms compete. Therefore, favoring local firms in the first period is the efficient way to increase the chance of a tough competition in the second period between providers and maximizing the intertemporal social welfare.

Implementation. The optimal sequential mechanisms, described in Proposition 1 and 3, can be implemented by a modified sequential first-price or second-period auction applying the implementation techniques developed by Naegelen and Mougeot (1998). The auctions have to be modified with respect to the standard tendering mechanism to take care of optimal discrimination in each period.

5 Discussion

5.1 Technological Adaptation and Endogenous Transferability

In the basic model, the global firm has the ability to transfer learning-by-doing across different cities. Implicitly, we assume that the learning accumulated by the global firm outside the city (external learning) is similar to the one gained by learning-by-doing in the city (internal learning). Nevertheless, these two different kinds of learning do not need to be the same, and learning-by-doing can be city-specific. In such context, the global firm may have to make some technological adaptation in order to transfer external learning to the local public good provision.[15]

In order to understand how the need for adaptation of external learning affects the optimal mechanism, we consider a slightly modified version of our model in which the global firm makes an investment to adapt the external learning to local conditions. Formally, we assume that the global firm exerts a noncontractible effort e at date (iv) in the Timing (i.e., before the public authority selects and pays firms in period 1) that increases the probability of transferring learning from outside markets. In addition, we suppose that the global firm incurs a cost that is increasing and convex in the level of effort. In this modified model, global firm's incentive to invest depends only on the first-period mechanism, since investment will be sunk in period 2.

In this setting, the global firm's investment in technological adaptation does not change the second-period optimal mechanism described in Proposition 1. It happens because the effort is sunk when this mechanism is designed. However, it introduces a new ingredient in the problem faced by the public authority in the first period. Indeed, the public authority would like to increase the effort of the global firm as this reduces its expected transfers to the providers. To induce high effort in technological adaptation from the global firm, the public authority has to select the global firm in period 1 with high probability. The public authority now faces a trade-off between favoring the local firm to foster future competition versus favoring the global firm to induce high technological adaptation. Adding this effect to the one described in Proposition 3, we can show that when the impact of the effort choice e on θ is sufficiently small, then the public authority favors the local firm in the first period.

[15] Such investment in technology adaptation can also be interpreted as an investment in multi-markets since the higher transferability is, the more likely the global firm will transfer knowledge from different markets.

Otherwise, it prefers to favor the global one.

5.2 Numerical Results

Proposition 4 shows that the first-period optimal procurement mechanism has to be biased in favor of the local firm to foster future competition, thereby reducing intertemporal expected transfers to public good providers. This result is valid if and only if equation (17) holds. Using numerical simulations, we show that (17) is satisfied for classical distribution functions that fulfill the conditional stochastic dominance assumption in the Section 2.2.

Not all classes of distribution functions satisfy the Maskin and Riley's conditional stochastic dominance condition.[16] Two very common classes of distribution functions, the Uniform and the Pareto ones, do fulfill conditional stochastic dominance assumption. We investigate whether equation (17) holds for the Uniform and the Pareto distributions.

An analytical inspection of the validity of expression (17) for the Uniform and the Pareto distributions is not an easy task. To overcome cumbersome computations, we provide numerical results using Matlab in which we find that equation (17) holds for the following two distribution functions.

Numerical Result 1 *Let Δ be defined as follows:*

$$\Delta \equiv \int_{\underline{c}_s}^{\overline{c}_s} c(1-F_s(c))f_s(c)dc \;-\; \frac{1}{2}\Bigg\{ \int_{\underline{c}_s}^{\overline{c}_s}\Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))} \widetilde{c} f_w(\widetilde{c})d\widetilde{c}\Big] f_s(c)dc - \int_{\underline{c}_w}^{\overline{c}_w}\Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))} \widetilde{c} f_s(\widetilde{c})d\widetilde{c}\Big] f_w(c)dc \Bigg\}. \tag{21}$$

We have $\Delta \leq 0$ when the distribution functions $F_s(c)$ and $F_w(c)$ take one the following forms:

- *Uniform distributions: Such that*

$$F_s(c) = \begin{cases} 0 & , \textit{if } c < \underline{c}_s \\ \frac{c-\underline{c}_s}{\overline{c}_s-\underline{c}_s} & , \textit{if } c \in [\underline{c}_s, \overline{c}_s] \\ 1 & , \textit{if } c > \overline{c}_s \end{cases} ; \qquad F_w(c) = \begin{cases} 0 & , \textit{if } c < \underline{c}_w \\ \frac{c-\underline{c}_w}{\overline{c}_w-\underline{c}_w} & , \textit{if } c \in [\underline{c}_w, \overline{c}_w] \\ 1 & , \textit{if } c > \overline{c}_w \end{cases} ; \tag{22}$$

  for $\underline{c}_s < \underline{c}_w$, $\overline{c}_s < \overline{c}_w$, and $(\overline{c}_s - \underline{c}_s) < (\overline{c}_w - \underline{c}_w)$;

- *Pareto distributions: Such that*

$$F_s(c) = \begin{cases} 1-\left(\frac{\underline{c}_s}{c}\right)^\gamma & , \textit{if } c \geq \underline{c}_s \\ 1 & , \textit{if } c < \underline{c}_s \end{cases} ; \qquad F_w(c) = \begin{cases} 1-\left(\frac{\underline{c}_w}{c}\right)^\gamma & , \textit{if } c \geq \underline{c}_w \\ 1 & , \textit{if } c < \underline{c}_w \end{cases} ; \tag{23}$$

[16] For instance, Weibull, Exponential and Normal distributions do not satisfy this condition.

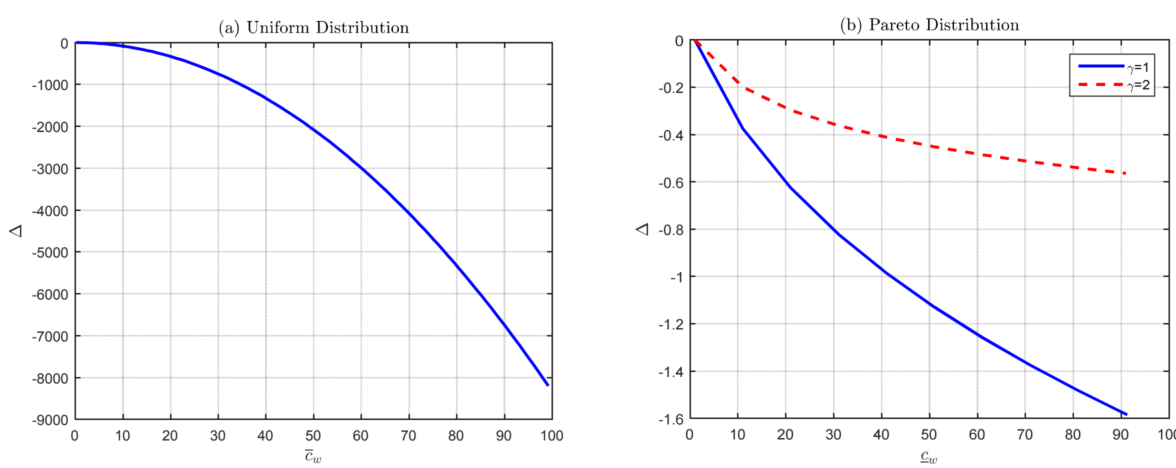
for $\underline{c}_s < \underline{c}_w$*, and integer* $\gamma \leq 2$.

The Numerical Result 1 shows that if $F_s(c)$ and $F_w(c)$ distribution functions belong to the Uniform and the Pareto distributions described above, then $\Delta \leq 0$. Since equation (17) is satisfied if and only if $\Delta \leq 0$, we can conclude that expression (17) holds for the Uniform and the Pareto distributions in equations (22) and (23).

Figure 1 panel (a) displays an example of the result stated in Numerical Result 1 for the Uniform distribution. In that panel, the computed values of Δ, defined in equation (21), are plotted against $\bar{c}_w$, holding $\underline{c}_s = 0$, $\bar{c}_s = 0.1$, and $\underline{c}_w = 0$. At the origin of that graph $\bar{c}_w = 0.1$, which means that $F_s(c)$ is equal to $F_w(c)$. Hence, $\Delta = 0$. However, when $\bar{c}_w$ increases, $F_s(c)$ starts to conditional-stochastically dominate $F_w(c)$, making $\Delta < 0$.

Panel (b) in Figure 1 reports numerical exercises for the Pareto distribution. The solid and the dashed lines display the numerical exercises for Pareto distributions with parameters $\gamma = 1$ and $\gamma = 2$, respectively. In that panel, the computed values of Δ are plotted against $\underline{c}_w$, holding $\underline{c}_s = 1$. At the origin of that graph $\bar{c}_w = 1$. As in the case above, that means that $F_s(c)$ is equal to $F_w(c)$, which makes $\Delta = 0$. However, when $\underline{c}_w$ raises, $F_s(c)$ begins to dominate conditional-stochastically $F_w(c)$, and we obtain $\Delta < 0$.

Figure 1: Numerical Example - Uniform and Pareto Distribution



The figure displays numerical examples of the result stated in Numerical Result 1 for the Uniform and the Pareto distributions in equations (22) and (23), according to the parameters described below. Panel (a) reports a numerical exercise for the Uniform distribution. In that panel, the computed values of Δ, defined in equation (21), are plotted against $\bar{c}_w$, holding $\underline{c}_s = 0$, $\bar{c}_s = 0.1$, and $\underline{c}_w = 0$. Panel (b) reports numerical exercises for the Pareto distributions with parameters γ equal to 1 and 2. The solid and the dashed lines display the numerical exercises for Pareto distributions with parameters $\gamma = 1$ and $\gamma = 2$, respectively. In that panel, the computed values of Δ are plotted against $\underline{c}_w$, holding $\underline{c}_s = 1$.

5.3 Existence of Learning-by-Doing and Transferability

The optimal sequential discriminatory mechanism characterized in this paper relies on the presence of learning-by-doing and global firm's transferability. In this section, we present some evidence supporting the existence of these components in public good provision and, therefore, the importance of designing optimal discriminatory policies.

We proceed in two steps. First, we derive some testable hypotheses from a framework where the authority relies on an unbiased first-price procurement auction (FPA).[17] We have opted for FPA rather than any other mechanism because public procurement auctions are often organized as first-price sealed auctions.[18] We then match these hypotheses with empirical studies and provide some foundations for the assumptions of learning-by-doing and global firm's transferability in the provision of public services.

5.3.1 Set up

We consider a modified version of the model described in Section 2. The main difference is that we assume that the mechanism used by the authority is an unbiased first-price procurement auction. Suppose that the authority organizes at dates (iii) and (ix) in the Timing, a first-price procurement auction to choose the public good provider.[19] In the first-price procurement auction, firms bid for the monetary transfer that they want to receive for the one period public good provision. The firm with the lowest bid provides the public good and receives a monetary transfer which corresponds to the value of his bid.

We assume that the weak distribution is an uniform distribution function on $[\underline{c}, \overline{c}]$, with $0 < \underline{c} < \overline{c}$, and the strong distribution is an uniform distribution function on $[0, \widetilde{c}]$, with $\underline{c} < \widetilde{c} < \overline{c}$ and $\widetilde{c} = \overline{c} - \underline{c}$. Those assumptions guarantee that $U[0, \widetilde{c}]$ conditionally stochastically dominates $U[\underline{c}, \overline{c}]$, as we assumed in Section 2.[20]

To simplify the analysis, we restrict the bids to be linear functions of production cost (see Krishna, 2002).

5.3.2 Testable hypotheses

We look at the empirical predictions which comes from the Perfect Bayesian Equilibrium (PBE) of the game, the relevant equilibrium concept in this setting. It is characterized by

[17] A complete treatment of this framework is derived in Barbosa and Boyer (2011) in which we name global firm as a private one, and local firm as a public one.

[18] See Laffont and Tirole (1993), Naegelen and Mougeot (1998), and Dimitri, Piga and Spagnolo (2006) for additional references on procurement practices.

[19] In some industries such as local transportation in France, firms bid for public subsidies to perform the provision of the services. The analysis developed in this paper also applies for the case of bidding for subsidies.

[20] Lee (2008) makes similar assumptions when studying bidding behavior of asymmetric firms in a procurement auction that the seller optimally grantees a right of first refusal (ROFR) to weak bidders.

backward induction. We find the empirical predictions of Bayesian Nash Equilibrium (BNE) in each possible contingency of the second-period competition. Then, we turn to the testable hypotheses of the BNE in first-period competition.

Second-Period Competition. The second-period competition takes place under three possible contingencies, which are described in Section 2.

We can show that in every contingency, the incumbent firm is less aggressive than the entrant one, and has higher probability of winning the second-period competition.

Intuitively, in the case that the firms have the same production cost, the incumbent-strong firm's bid is higher than the entrant-weak one. As the strong firm knows that it is likely to have lower cost than its competitor, it does not need to be too aggressive in the competition in order to win it. Such strong and weak firms' behavior in static auctions has been also studied by Maskin and Riley (2000), Lee (2008) and others, whose theoretical predictions have been supported empirically by De Silva, Dunne and Kosmopoulou (2003), De Silva, Jeitschko and Kosmopoulou (2005), and De Silva, Kosmopoulou and Lamarche (2009). Despite the fact that the strong firm is not very aggressive in the competition (i.e. higher bidding function), it has higher probability of winning the auction than the weak firm. The incumbent firm has the highest probability of winning, even though it asks the public authority for a higher monetary transfer to provide the public good.

This result provides the following testable hypotheses:

Hypothesis 1 *In the second-period competition, the incumbent firm has higher probability of winning than the entrant in industries with learning-by-doing.*

Hypothesis 1 arises due to the existence of learning-by-doing. It can be interpreted as follows: the higher firm's learning-by-doing in a certain industry, the more likely that the incumbent firm wins the competition against an entrant.[21]

Several studies have found empirical evidence supporting Hypothesis 1. The water sector, for instance, is recognized as a sector in which the incumbent enjoys learning-by-doing (see, Aubert, Bontemps and Salanié, 2006). It is consistent with GEA-ENGREF (2002), a recent report on contracts of water concession in France, which documents that in 78 percent of auctions for concession, the incumbent is never replaced. It is also consistent with the evidence documented by Szymanski (1996) in the refuse collection services in UK. Szymanski shows that where private contractors are already established, competitive tendering is likely to continue.

[21] Learning-by-doing can also be related to the duration that a firm is providing a certain public service. In this case, Hypothesis 1 can be rewritten as follows: the longer the incumbent is the provider of the public good, the higher is the probability that it will win the competition against an entrant firm for a new contract of the public service.

Where public firms (DSOs) have retained the contract, compulsory competitive tendering has had a relatively small impact. In the road construction industry, De Silva (2005) and De Silva, Jeitschko and Kosmopoulou (2005) show that the higher the potential synergies in recurring contracts, the higher is the probability that incumbent firms win procurement auctions.

If we compare the second-period expected transfer under global firm ownership with respect to local one, we obtain the following hypothesis.

Hypothesis 2 *The expected second-period transfer when the first-period provider is a global firm is higher than the second-period expected transfer when the first-period provider is a local firm in industries with global firm's transferability.*

Hypothesis 2 comes from the existence of global firm's transferability. Global firm's transferability bounds the expected transfers to the incumbent local firm, whereas it increases the expected transfers to the global firm. This result is consistent with Proposition 2.

Analyzing the competition between global and local firms in a competition for public services, the key difference between firms is that global firms can serve several markets, whereas the local one only provides the local public good to the local city. If we interpret the global firm as a private firm, and local firm as local public firm, we can rewrite Hypothesis 2 as follows: the expected second-period transfer under private ownership is higher than the second-period expected transfer under local public ownership. This is consistent with Bontemps, Martimort and Thomas (2011), who analyze the regulated price of potable water in France and show that prices of water in cities with private ownership are higher on average than in cities with public ownership.

First-Period Competition. In a first-period competition, when choosing the optimal strategy, both firms anticipate the dynamic effect of winning in the first period on the second-period competition. In particular, the global firm anticipates that by winning the first-period competition, it will be the most efficient competitor in the second-period. By contrast, the local firm is less likely to enjoy such rents in the second-period competition because it may face a global firm with external learning.

The equilibrium outcome of this competition will be the following: the global firm will be more aggressive than the local one in the first-period competition. This implies that the global firm will have a higher probability of winning the first competition than the local one. Consequently, the global firm is likely to be the unique strong firm in the second-period competition. Comparing the first-period expected transfer that the public authority expects to pay with the second-period expected transfer, we obtain the following hypothesis.

Hypothesis 3 *The first-period expected transfer to the public good provider is lower than the second-period expected transfer in industries with learning-by-doing and global firm's transferability.*

Hypothesis 3 comes from the existence of learning-by-doing and transferability. The intuition for this result is the following: learning-by-doing gives the incumbent firm an advantage over the entrant in a subsequent competition, which translates into higher probability of winning and higher profit, and high monetary transfer for the second-period public good provider. Competing firms anticipate these benefits of being incumbent. Hence, they fiercely compete for the first-period competition, producing low first-period profit for firms and, therefore, low public monetary transfer for the first-period public good provider.

Similar bidding behavior in sequential auctions has been studied by Branco (1997) and Jeitschko and Wolfstetter (2002). They show that bidders that stand to realize synergies will bid more aggressively, leading to the well-known increasing price anomaly (expected price increase from the first to the second period) in procurement auctions. De Silva (2005) finds supporting evidence for these theoretical results, showing that incumbents firms bidding in their own division and in different divisions bid more aggressive than any other bidder. Gandal (1997), studying the auctions for cable television licenses in Israel, also document evidence consistent with Hypothesis 3. In particular, he finds that spatial synergies and positive interdependencies among franchises make competition more intense in early rounds of sequential auctions for cable television licenses.

Hypothesis 3 is also consistent with Gagnepain, Ivaldi and Martimort (2013), who analyze the public subsidies to providers of local public transportation in France. They show that subsidies to operators have been increasing over time. In addition, Shaoul (1997) who investigating the privatized firms in water and sewerage companies of England and Wales also find evidence supporting Hypothesis 3. Shaoul (1997) finds that the prices charged by private firms in their second period contract of water provision is substantially higher than the prices charged by private firms in their first period contract. These empirical implications are also consistent with the evidence for the water sector surveyed by Renzetti and Dupont (2004).

6 Concluding Remarks

In this paper we study the long-run impact of procurement discrimination on market structure and future competition in industries where learning-by-doing makes firms more efficient over time. To investigate these dynamic aspects, we consider a two-period model of procurement design in which two types of firms compete for public good provision: local and global firms. In each period, the public authority chooses the procurement mechanism that maximizes the social welfare net of the cost of public funds. Firms are ex-ante symmetric with respect to the first-period cost distribution, and both firm types benefit from learning-by-doing in the form of cost reduction over time, if they provide the public good in the previous period. A global firm has synergy advantages over a local one as it may have access to learning-by-doing even when it is not locally incumbent: learning-by-doing may be transferable from external markets. As a main result, we find that the benevolent authority has to bias the mechanism in every period in favor of the least efficient firm. This bias fosters competition and reduces transfers to the provider. As the least efficient firm is more often a local firm, our result calls for a bias favoring local firms.

Appendix

Proof of Lemma 1

We first compute $U_L^C(p_{L1}, p_{G1})$, and then $U_G^C(p_{L1}, p_{G1})$. By definition, $U_L^C(p_{L1}, p_{G1})$ is equal to

$$U_L^C(p_{L1}, p_{G1}) = p_{L1}\Big\{(1-\theta)E_{c_{L2}}\big[U_{L2}(c_{L2}, X=1)\big] + \theta E_{c_{L2}}\big[U_{L2}(c_{L2}, X=2)\big]\Big\}$$

$$+p_{G1}E_{c_{L2}}\big[U_{L2}(c_{L2}, X=3)\big],$$

where $U_{L2}(c_{L2}, X)$ is defined in (5). By Proposition 1(i) and equation (5), we obtain that

$$\overline{U} \equiv E_{c_{L2}}\big[U_{L2}(c_{L2}, X=1)\big] = E_{c_{L2}}\Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=1)} Q_{L2}(s_{L2}, X=1)ds_{L2}\Big]. \tag{24}$$

By Proposition 1(ii) and equation (4)

$$\begin{aligned} Q_{L2}(c_{L2}, X=1) &= E_{c_{G2}}[p_{L2}(s_{L2}, c_{G2}, X=1)] \\ &= E_{c_{G2}}[1\{\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=1)) \leq c_{G2}\}] \\ &= 1 - F_{G2}(\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=1))), \end{aligned} \tag{25}$$

where $1\{.\}$ is an indicator function which is equal to 1, if $\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=1)) \leq c_{G2}$, and zero, otherwise.

By replacing (25) in (24), we obtain that

$$\begin{aligned}
\overline{U} &= E_{c_{L2}}\Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=1)} 1 - F_{c_{G2}}(\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=1)))ds_{L2}\Big] \\
&= \int_{\underline{c_{L2}}(X=1)}^{\overline{c_{L2}}(X=1)} \Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=1)} 1 - F_{G2}(\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=1)))ds_{L2}\Big] f_{L2}(c_{L2}|X=1)dc_{L2} \\
&= \int_{\underline{c}_s}^{\bar{c}_s} (1 - F_w(\Phi_w^{-1}(\Phi_s(c))))F_s(c)dc. \qquad (26)
\end{aligned}$$

as $F_{G2} = F_w$ and $F_{L2} = F_s$ when $X = 1$, and after an integration by parts.

Similarly,

$$\begin{aligned}
\tilde{U} &\equiv E_{c_{L2}}\big[U_{L2}(c_{L2}, X=2)\big] \\
&= E_{c_{L2}}\Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=2)} Q_{L2}(s_{L2}, X=2)ds_{L2}\Big] \\
&= \int_{\underline{c_{L2}}(X=2)}^{\overline{c_{L2}}(X=2)} \Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=2)} 1 - F_{G2}(s_{L2}|X=2)ds_{L2}\Big] f_{L2}(c_{L2}|X=2)dc_{L2} \\
&= \int_{\underline{c}_s}^{\bar{c}_s} (1 - F_s(c))F_s(c)dc, \qquad (27)
\end{aligned}$$

as $F_{G2} = F_{L2} = F_s$ when $X = 2$.

Finally, we have that

$$\begin{aligned}
\underline{U} &\equiv E_{c_{L2}}\big[U_{L2}(c_{L2}, X=3)\big] \\
&= E_{c_{L2}}\Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=3)} Q_{L2}(s_{L2}, X=3)ds_{L2}\Big] \\
&= \int_{\underline{c_{L2}}(X=3)}^{\overline{c_{L2}}(X=3)} \Big[\int_{c_{L2}}^{\overline{c_{L2}}(X=3)} 1 - F_{G2}(\Phi_{G2}^{-1}(\Phi_{L2}(s_{L2}, X=3)))ds_{L2}\Big] f_{L2}(c_{L2}|X=3)dc_{L2} \\
&= \int_{\underline{c}_w}^{\bar{c}_w} (1 - F_s(\Phi_s^{-1}(\Phi_w(c))))F_w(c)dc, \qquad (28)
\end{aligned}$$

as $F_{G2} = F_s$ and $F_{L2} = F_w$ when $X = 3$.

Using expressions (26), (27) and (28), we obtain that $U_L^C(1,0) = \theta\tilde{U} + (1-\theta)\overline{U}$ and $U_L^C(0,1) = \underline{U}$.

We now turn to the characterization of $U_G^C(p_{L1}, p_{G1})$. By definition, $U_L^C(p_{L1}, p_{G1})$ is equal to

$$U_G^C(p_{L1}, p_{G1}) = p_{L1}\Big\{(1-\theta)E_{c_{G2}}\big[U_{G2}(c_{G2}, X=1)\big] + \theta E_{c_{G2}}\big[U_{G2}(c_{G2}, X=2)\big]\Big\}$$
$$+p_{G1}E_{c_{L2}}\big[U_{G2}(c_{G2}, X=3)\big],$$

where $U_{G2}(c_{G2}, X)$ is defined in (5).

Given the symmetry of the states, for the global firm we get the continuation payoff in each state X:

$$E_{c_{G2}}\big[U_{G2}(c_{G2}, X=1)\big] = E_{c_{L2}}\big[U_{L2}(c_{L2}, X=3)\big] = \underline{U}; \tag{29}$$

$$E_{c_{G2}}\big[U_{G2}(c_{G2}, X=2)\big] = E_{c_{L2}}\big[U_{L2}(c_{L2}, X=2)\big] = \tilde{U}; \tag{30}$$

$$E_{c_{G2}}\big[U_{G2}(c_{G2}, X=3)\big] = E_{c_{L2}}\big[U_{L2}(c_{L2}, X=1)\big] = \overline{U}. \tag{31}$$

Using the expressions (29) to (31), we obtain that $U_G^C(1,0) = \theta\tilde{U} + (1-\theta)\underline{U}$ and $U_G^C(0,1) = \overline{U}$. ■

Proof of Lemma 2

We first compute the public authority's continuation payoff, and then we turn to expected net continuation consumers surplus (consumers surplus minus expected payment to firms). The public authority's continuation payoff $W^C(p_{L1}, p_{G1})$ is given by

$$W^C(p_{L1}, p_{G1}) = p_{L1}\big[(1-\theta)W_2(X=1) + \theta W_2(X=2)\big] + p_{G1}W_2(X=3). \tag{32}$$

We need to compute the public authority's payoff in each state X of period 2, $W_2(X)$. By equation (7), $W_2(X)$ at state X is given by

$$\begin{aligned} W_2(X) &= \int_{\Delta_2(X)} \Bigg\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{L2}|X)} \right] p_{L2}(c_2, X) + \\ &\quad + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} \right] p_{G2}(c_2, X) \Bigg\} f_2(c_2|X)dc_2, \end{aligned}$$

where $p_{L2}(c_2, X)$ and $p_{G2}(c_2, X)$ are characterized in Proposition 1. After some algebraic manipulations, we obtain that

$$W_2(X) = S_2(X) + (1+\lambda-\alpha)(U_2^L(X) + U_2^G(X)), \tag{33}$$

where,

$$S_2(X) \equiv S - (1+\lambda)\int_{\Delta_2(X)} \Big[c_{L2}p_{L2}(c_2, X) + c_{G2}p_{G2}(c_2, X)\Big] f_2(c_2|X)dc_2. \tag{34}$$

$U_2^L(X)$ is defined as,

$$U_2^L(X) \equiv \int_{\Delta_2(X)} \left[\frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{L2}|X)} p_{L2}(c_2, X) \right] f_2(c_2|X) dc_2$$
$$= \int_{\underline{c_{L2}}(X)}^{\overline{c_{L2}}(X)} F_{L2}(c_{L2}|X)(1 - F_{G2}(\Phi_{G2}^{-1}(\Phi_{L2}(c_{L2}, X)))dc_{L2}, \tag{35}$$

which follows by the results derived in Proposition 1 and in Lemma 2, and from equation (4).

$U_2^G(X)$ is defined as,

$$U_2^G(X) \equiv \int_{\Delta_2(X)} \left[\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} p_{G2}(c_2, X) \right] f_2(c_2|X) dc_2$$
$$= \int_{\underline{c_{G2}}(X)}^{\overline{c_{G2}}(X)} F_{G2}(c_{G2}|X)(1 - F_{L2}(\Phi_{L2}^{-1}(\Phi_{G2}(c_{G2}, X)))dc_{G2}, \tag{36}$$

which follows by the same algebraic manipulations described above.

From Proposition 1 and Lemma 2, $F_{G2} = F_w$ and $F_{L2} = F_s$ when $X = 1$. Hence, $p_{L2}(c_2, X = 1) = 1 - p_{G2}(c_2, X = 1) = 1\{\Phi_s(c_{L2}) \leq \Phi_w(c_{G2})\}$, where $1\{.\}$ is an indicator function which is equal to 1, if $\Phi_s(c_{L2}) \leq \Phi_w(c_{G2})$, and zero, otherwise. Therefore,

$$S_2(X = 1) \equiv S - (1 + \lambda) \Bigg\{ \int_{\underline{c}_w}^{\overline{c}_w} \int_{\underline{c}_s}^{\overline{c}_s} \Big[c_{L2} 1\{\Phi_s(c_{L2}) \leq \Phi_w(c_{G2})\} \Big] f_w(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2} +$$
$$+ \int_{\underline{c}_w}^{\overline{c}_w} \int_{\underline{c}_s}^{\overline{c}_s} \Big[c_{G2} 1\{\Phi_s(c_{L2}) \geq \Phi_w(c_{G2})\} \Big] f_w(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2} \Bigg\}. \tag{37}$$

As

$$\int_{\underline{c}_s}^{\overline{c}_s} \Big[c_{L2} 1\{\Phi_s(c_{L2}) \leq \Phi_w(c_{G2})\} \Big] f_s(c_{L2}) dc_{L2} = E_{c_{L2}}[c_{L2} \cdot 1\{c_{L2} \leq \Phi_s^{-1}(\Phi_w(c_{G2}))\}|c_{G2}]$$
$$= \int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c_{G2}))} \widetilde{c} f_s(\widetilde{c}) d\widetilde{c}. \tag{38}$$

Similarly,

$$\int_{\underline{c}_w}^{\overline{c}_w} \Big[c_{G2} 1\{\Phi_s(c_{L2}) \geq \Phi_w(c_{G2})\} \Big] f_w(c_{G2}) dc_{G2} = E_{c_{G2}}[c_{G2} \cdot 1\{c_{G2} \leq \Phi_w^{-1}(\Phi_s(c_{L2}))\}|c_{L2}]$$
$$= \int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c_{L2}))} \widetilde{c} f_w(\widetilde{c}) d\widetilde{c}. \tag{39}$$

Replacing (38) and (39) in (37), we obtain that

$$S_2(X=1) = S-(1+\lambda)\left\{\int_{\underline{c}_w}^{\bar{c}_w}\Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))}\widetilde{c}f_s(\widetilde{c})d\widetilde{c}\Big]f_w(c)dc+\int_{\underline{c}_s}^{\bar{c}_s}\Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))}\widetilde{c}f_w(\widetilde{c})d\widetilde{c}\Big]f_s(c)dc\right\}. \tag{40}$$

As

$$\int_{\underline{c}_w}^{\bar{c}_w}\Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))}\widetilde{c}f_s(\widetilde{c})d\widetilde{c}\Big]f_w(c)dc = E_w\big[E_s[c\cdot 1\{c\leq \Phi_s^{-1}(\Phi_w(c''))\}|c'']\big],$$

and

$$\int_{\underline{c}_s}^{\bar{c}_s}\Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))}\widetilde{c}f_w(\widetilde{c})d\widetilde{c}\Big]f_s(c)dc = E_s\big[E_w[c''\cdot 1\{c''\leq \Phi_w^{-1}(\Phi_s(c))\}|c]\big],$$

and then

$$S_2(X=1) = \underline{S}, \tag{41}$$

defined in equation (12).

Note that,

$$U_2^L(X=1) = \int_{\underline{c}_s}^{\bar{c}_s} F_s(c_{L2})(1-F_w(\Phi_w^{-1}(\Phi_s(c_{L2})))dc_{L2}, \tag{42}$$

then $U_2^L(X=1)=\overline{U}$, which is defined Lemma 2.

Similarly,

$$U_2^G(X=1) = \int_{\underline{c}_w}^{\bar{c}_w} F_w(c_{G2})(1-F_s(\Phi_s^{-1}(\Phi_w(c_{G2})))dc_{G2}, \tag{43}$$

then $U_2^G(X=1)=\underline{U}$, which is defined Lemma 2.

By replacing in (41), (42) and (43) in equation (33), we obtain that

$$W_2(X=1) = \underline{S}-(1+\lambda-\alpha)(\underline{U}+\overline{U}). \tag{44}$$

Hence, $W_2(X=1)=\underline{W}$, which is defined in equation (14).

Given the symmetry of states $X=1$ and $X=3$, and applying similar algebraic manipulations, we obtain that $S_2(X=3)=\underline{S}$, $U_2^L(X=3)=\underline{U}$ and $U_2^G(X=3)=\overline{U}$. By replacing those expressions in equation (33), we obtain that

$$W_2(X=3) = \underline{S}-(1+\lambda-\alpha)(\underline{U}+\overline{U}). \tag{45}$$

Hence, $W_2(X=3)=\underline{W}$, which is defined in equation (14).

Similarly, from Proposition 1 and Lemma 2, $F_{G2}=F_{L2}=F_s$ when $X=2$. Hence, $p_{L2}(c_2,X=2)=1-p_{G2}(c_2,X=2)=1\{c_{L2}\leq c_{G2}\}$, where $1\{.\}$ is an indicator function which is equal to 1, if $c_{L2} \leq c_{G2}$, and zero, otherwise. Therefore,

$$\begin{aligned} S_2(X=2) \;\; \equiv \;\; & S - (1+\lambda)\Bigg\{ \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_s}^{\overline{c}_s} \Big[c_{L2} 1\{c_{L2} \leq c_{G2}\}\Big] f_s(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2} + \\ & + \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_s}^{\overline{c}_s} \Big[c_{G2} 1\{c_{L2} \geq c_{G2}\}\Big] f_s(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2} \Bigg\}. \end{aligned} \tag{46}$$

As

$$\begin{aligned} \int_{\underline{c}_s}^{\overline{c}_s} \Big[1\{c_{L2} \leq c_{G2}\}\Big] f_s(c_{G2}) dc_{G2} &= E_{c_{G2}}[1\{c_{L2} \leq c_{G2}\} | c_{L2}] \\ &= 1 - F_s(c_{L2}). \end{aligned} \tag{47}$$

Similarly,

$$\begin{aligned} \int_{\underline{c}_s}^{\overline{c}_s} \Big[1\{c_{L2} \geq c_{G2}\}\Big] f_s(c_{L2}) dc_{L2} &= E_{c_{L2}}[1\{c_{G2} \geq c_{L2}\} | c_{G2}] \\ &= 1 - F_s(c_{G2}). \end{aligned} \tag{48}$$

Replacing (47) and (48) in (46), we obtain that

$$S_2(X=2) = S - 2(1+\lambda) \int_{\underline{c}_s}^{\overline{c}_s} c(1 - F_s(c)) f_s(c) dc. \tag{49}$$

Note that

$$\int_{\underline{c}_s}^{\overline{c}_s} c(1 - F_s(c)) f_s(c) dc = E_s\big[E_s[c \cdot 1\{c \leq c'\} | c']\big]$$

Hence,

$$S_2(X=2) = \overline{S}, \tag{50}$$

defined in equation (11).

Note that,

$$U_2^L(X=2) = \int_{\underline{c}_s}^{\overline{c}_s} F_s(c_{L2})(1 - F_s((c_{L2})) dc_{L2}, \tag{51}$$

then $U_2^L(X=2) = \tilde{U}$, which is defined Lemma 2.

Similarly,

$$U_2^G(X=1) = \int_{\underline{c}_s}^{\overline{c}_s} F_s(c_{G2})(1 - F_s((c_{G2})) dc_{G2}, \tag{52}$$

then $U_2^G(X=2) = \tilde{U}$, which is defined Lemma 2.

By replacing in (50), (51) and (52) in equation (33), we obtain that

$$W_2(X=2) = \overline{S} - (1+\lambda-\alpha)2\tilde{U}. \tag{53}$$

Hence, $W_2(X=2) = \overline{W}$, which is defined in equation (13).

Having computed the public authority's payoff in each state X of period 2, $W_2(X)$, we can compute public authority's continuation payoff. To do so, we have to replace (44), (45) and (53) in (32) such that

$$W^C(1,0) = \theta\overline{W} + (1-\theta)\underline{W}, \qquad \text{and} \qquad W^C(0,1) = \underline{W}. \tag{54}$$

We now compute the expected net continuation consumers surplus (consumers surplus minus expected payment to firms), $S^C(p_{L1}, p_{G1})$, which is given by the following expression:

$$S^C(p_{L1}, p_{G1}) = p_{L1}\big[(1-\theta)S_2(X=1) + \theta S_2(X=2)\big] + p_{G1}S_2(X=3). \tag{55}$$

In the computation of $W_2(X)$, we showed that

$$S_2(X=1) = S_2(X=3) = \underline{S} \qquad \text{and} \qquad S_2(X=2) = \overline{S}. \tag{56}$$

Plugging (56) in (55), we obtain $S^C(1,0) = \theta\overline{S} + (1-\theta)\underline{S}$ and $S^C(0,1) = \underline{S}$. ■

Proof of Proposition 2

We first show that $\overline{W} \geq \underline{W}$. Then we show that $\overline{S} \geq \underline{S}$ if, and only if, equation (17) holds.

Part (i): $\overline{W} \geq \underline{W}$.

From Proof of Lemma 2, we obtained the public authority's payoff in each state X of period 2, $W_2(X)$, which is given by

$$\begin{aligned} W_2(X) \quad = \quad & \int_{\Delta_2(X)} \Bigg\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_{L2}(c_{L2}|X)}{f_{L2}(c_{L2}|X)} \right] p_{L2}(c_2, X) + \\ & + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_{G2}(c_{G2}|X)}{f_{G2}(c_{G2}|X)} \right] p_{G2}(c_2, X) \Bigg\} f_2(c_2|X)dc_2, \end{aligned} \tag{57}$$

such that $W_2(X=2) = \overline{W}$ and $W_2(X=1) = W_2(X=3) = \underline{W}$, when $p_{L2}(c_2, X)$ and $p_{G2}(c_2, X)$ are the optimal awarding probability characterized in Proposition 1.

From Proposition 1 and Lemma 2, $F_{G2} = F_{L2} = F_s$ when $X = 2$. Hence, $p_{L2}(c_2, X=2) = 1 - p_{G2}(c_2, X=2) = 1\{c_{L2} \leq c_{G2}\}$, where $1\{.\}$ is an indicator function which is equal to 1, if $c_{L2} \leq c_{G2}$, and zero, otherwise. Therefore, value function of the public authority at state $X = 2$ is given by

$$\begin{aligned} \overline{W} &= \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_s}^{\overline{c}_s} \left\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_s(c_{L2})}{f_s(c_{L2})} \right] 1\{c_{L2} \leq c_{G2}\} + \right. \\ &\quad \left. + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_s(c_{G2})}{f_s(c_{G2})} \right] 1\{c_{G2} \leq c_{L2}\} \right\} f_s(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2}. \end{aligned}$$

As $p_{L2}(c_2, X = 2) = 1 - p_{G2}(c_2, X = 2) = 1\{c_{L2} \leq c_{G2}\}$ are the optimal awarding probability in state $X = 2$, then

$$\begin{aligned} \overline{W} &\geq \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_s}^{\overline{c}_s} \left\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_s(c_{L2})}{f_s(c_{L2})} \right] 1\{c_{L2} \leq \Phi_w^{-1}(\Phi_s(c_{G2}))\} + \right. \\ &\quad \left. + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_s(c_{G2})}{f_s(c_{G2})} \right] 1\{c_{G2} \leq \Phi_s^{-1}(\Phi_w(c_{G2}))\} \right\} f_s(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2}, \end{aligned}$$

since $1\{c_{L2} \leq \Phi_w^{-1}(\Phi_s(c_{G2}))\} = p_{L2}(c_2, X = 3) = 1 - p_{G2}(c_2, X = 3)$ are the optimal awarding probability in state $X = 3$, where $1\{.\}$ is an indicator function which is equal to 1, if $\Phi_w(c_{L2}) \leq \Phi_s(c_{G2})$, and zero, otherwise.

The conditional stochastic dominance assumption implies that $\frac{F_s(c_{L2})}{f_s(c_{L2})} > \frac{F_w(c_{L2})}{f_w(c_{L2})}$. Then, we obtain that

$$\begin{aligned} \overline{W} &> \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_s}^{\overline{c}_s} \left\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_w(c_{L2})}{f_w(c_{L2})} \right] 1\{c_{L2} \leq \Phi_w^{-1}(\Phi_s(c_{G2}))\} + \right. \\ &\quad \left. + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_s(c_{G2})}{f_s(c_{G2})} \right] 1\{c_{G2} \leq \Phi_s^{-1}(\Phi_w(c_{G2}))\} \right\} f_s(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2}. \end{aligned} \tag{58}$$

The first-order stochastic dominance, $F_s(c) > F_w(c)$, implies that the right-side of equation (58) is diminished when replacing the distribution function $f_s(c_{L2})$ by $f_w(c_{L2})$, and the interval of integration from $[\underline{c}_s, \overline{c}_s]$ by $[\underline{c}_w, \overline{c}_w]$. Therefore,

$$\begin{aligned} \overline{W} &> \int_{\underline{c}_s}^{\overline{c}_s} \int_{\underline{c}_w}^{\overline{c}_w} \left\{ \left[S - (1+\lambda)c_{L2} - (1+\lambda-\alpha)\frac{F_w(c_{L2})}{f_w(c_{L2})} \right] 1\{c_{L2} \leq \Phi_w^{-1}(\Phi_s(c_{G2}))\} + \right. \\ &\quad \left. + \left[S - (1+\lambda)c_{G2} - (1+\lambda-\alpha)\frac{F_s(c_{G2})}{f_s(c_{G2})} \right] 1\{c_{G2} \leq \Phi_s^{-1}(\Phi_w(c_{G2}))\} \right\} f_w(c_{G2}) f_s(c_{L2}) dc_{G2} dc_{L2} \\ &= \underline{W}, \end{aligned}$$

as $1\{c_{L2} \leq \Phi_w^{-1}(\Phi_s(c_{G2}))\} = p_{L2}(c_2, X = 3) = 1 - p_{G2}(c_2, X = 3)$ are the optimal awarding probability in state $X = 3$, when $F_{G2} = F_s$ and $F_{L2} = F_w$.

Because $\theta > 0$, $W^C(1, 0) > W^C(0, 1)$, where $W^C(p_{L1}, p_{G1})$ is defined in equation (32) and computed in (54).

Part (ii): $\overline{S} \geq \underline{S}$ if, and only if, equation (17) holds.

By definition in equations (11) and (12), we know that

$$\overline{S} \equiv S - 2(1+\lambda)E_s\big[E_s[c \cdot 1\{c \leq c'\}|c']\big],$$

$$\underline{S} \equiv S - (1+\lambda)\Big[E_s\big[E_w[c'' \cdot 1\{c'' \leq \Phi_w^{-1}(\Phi_s(c))\}|c]\big] + E_w\big[E_s[c \cdot 1\{c \leq \Phi_s^{-1}(\Phi_w(c''))\}|c'']\big]\Big],$$

From Proof of Lemma 2, we obtained

$$E_s\big[E_w[c'' \cdot 1\{c'' \leq \Phi_w^{-1}(\Phi_s(c))\}|c]\big] = \int_{\underline{c}_s}^{\overline{c}_s} \Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))} \widetilde{c} f_w(\widetilde{c}) d\widetilde{c}\Big] f_s(c) dc, \tag{59}$$

$$E_w\big[E_s[c \cdot 1\{c \leq \Phi_s^{-1}(\Phi_w(c''))\}|c'']\big] = \int_{\underline{c}_w}^{\overline{c}_w} \Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))} \widetilde{c} f_s(\widetilde{c}) d\widetilde{c}\Big] f_w(c) dc, \tag{60}$$

and

$$E_s\big[E_s[c \cdot 1\{c \leq c'\}|c']\big] = \int_{\underline{c}_s}^{\overline{c}_s} c(1 - F_s(c)) f_s(c) dc. \tag{61}$$

By replacing equations (59), (60) and (61) in $\overline{S}$ and $\underline{S}$, we obtain that $\overline{S} \geq \underline{S}$ if, and only, if

$$\begin{aligned} \int_{\underline{c}_s}^{\overline{c}_s} c(1 - F_s(c)) f_s(c) dc \quad \leq \quad & \frac{1}{2}\Bigg\{ \int_{\underline{c}_s}^{\overline{c}_s} \Big[\int_{\underline{c}_w}^{\Phi_w^{-1}(\Phi_s(c))} \widetilde{c} f_w(\widetilde{c}) d\widetilde{c}\Big] f_s(c) dc + \\ & + \int_{\underline{c}_w}^{\overline{c}_w} \Big[\int_{\underline{c}_s}^{\Phi_s^{-1}(\Phi_w(c))} \widetilde{c} f_s(\widetilde{c}) d\widetilde{c}\Big] f_w(c) dc \Bigg\}, \end{aligned}$$

which is the condition expressed in equation (17).

As $\theta > 0$, that implies that $S^C(1, 0) > S^C(0, 1)$, where $S^C(p_{L1}, p_{G1})$ is defined in equation (55) and computed in (56). ■

Proof of Proposition 3

The proof that the mechanism described in Proposition 3 is incentive compatible and individually rational is standard as in Proposition 1. However, it remains to be shown that the allocation rule described by equation (20) solves the public authority's problem P_{II}.

To do so, first notice that allocation rule in (20) is an optimal mechanism since it separately maximizes the two terms in P_{II} over all $p_1(c_1) = (p_{L1}(c_1), p_{G1}(c_1))$ in Δ_1. In particular, it gives positive weight only to nonnegative and maximal terms in third term of that expression. This implies that the maximized value of the intertemporal social welfare P_{II} is

$$S + E_{c_{L1},c_{G1}}\big[\max\{\overline{S} + (1-\theta)\underline{S} - \Phi_1(c_{L1}), \underline{S} - \Phi_1(c_{G1})\}\big].$$

In other words, it is the gross consumer surplus in period 1, S, plus the expectation of the highest continuation net consumers surplus, which is the continuation consumer surplus, $S^C(.,.)$ described in Lemma 2, minus the virtual cost in period 1, $\Phi_1(c_{i1})$ defined in Proposition 3. ■

Proof of Proposition 4

Define $\Omega_1(c_{L1}, c_{G1})$ as the net social benefit of selecting the local firm with respect to the global one in period 1 for a given profile of revealed costs (c_{L1}, c_{G1}). Thus,

$$\Omega_1(c_{L1}, c_{G1}) = \theta\overline{S} + (1-\theta)\underline{S} - \Phi_1(c_{L1}) - (\underline{S} - \Phi_1(c_{G1})) = \theta(\overline{S} - \underline{S}) + \Phi_1(c_{G1}) - \Phi_1(c_{L1}),$$

where $\Phi_1(c_{i1}) = (1+\lambda)c_{i1} + (1+\lambda-\alpha)\frac{F_w(c_{i1})}{f_w(c_{i1})}$ for all i.

First, notice that according to Proposition 3, if $\Omega_1(c_{L1}, c_{G1}) \geq 0$, then the public authority optimally selects the local firm to be the local public provider in period 1. Otherwise, the global firm is selected.

Second, the function $\Omega_1(c_{L1}, c_{G1})$ is continuous in (c_{L1}, c_{G1}), increasing in c_{L1}, and decreasing in c_{G1}. These properties come from the assumption that hazard rate function $\frac{F_{it}(c)}{f_{it}(c)}$ is continuous and non decreasing in c, for all i.

Having characterized the function $\Omega_1(.,.)$, let us characterize optimal discrimination policy, and the threshold $\overline{c}_{L1}$ described in Proposition 4. Doing so, first note that, when the vector of revealed costs (c_{L1}, c_{G1}) is such that $c_{G1} = c_{L1}$, then $\Omega_1(c_{L1}, c_{G1}) < 0$ since $\overline{S} > \underline{S}$, under the assumptions that equation (17) holds (by Proposition 2).

As $\Omega_1(.,.)$ is decreasing in $c_{L1} \in (\underline{c}_w, \overline{c}_w)$, by continuity, there exists $\overline{c}_{L1} > c_{G1}$, such that the local firm is selected to be the public good provider with probability one when $c_{L1} \leq \overline{c}_{L1}$. $\overline{c}_{L1}$ depends on c_{G1} since they jointly determine the value of the function $\Omega_1(.,.)$. In particular, note that if $\Omega_1(\overline{c}_w, c_{G1}) \geq 0$, then for any local firm's revealed cost c_{L1}, the local firm is always selected. When $\Omega_1(\overline{c}_w, c_{G1}) < 0$, by continuity and monotonicity of $\Omega_1(.,.)$ in c_{L1}, there exists $\overline{c}_{L1} \in (c_{G1}, \overline{c}_w)$, such that for any $c_{L1} \leq \overline{c}_{L1}$, then $\Omega_1(c_{L1}, c_{G1}) \geq 0$, so the local firm is selected to be the public good provider in period 1. Otherwise, for any $c_{L1} > \overline{c}_{L1}$, we have that

$\Omega_1(c_{L1}, c_{G1}) < 0$, so the global one is selected. In this case, $\bar{c}_{L1}$ is implicity defined by the expression $\Omega_1(\bar{c}_{L1}, c_{G1}) = 0$, which defines $\bar{c}_{L1}$ implicity as a function of c_{G1}. ■

Codes of Numerical Result 1

The Matlab codes below were used in the numerical simulations to show that equation (17) is satisfied for the uniform and the pareto distributions described in equations (22) and (23). We start by presenting the codes for uniform distribution, and then we show the ones for the pareto distributions. Those codes were also used to generate numerical examples in Figure 1.

```
%------------------------------------------------------------------------%
% Discrimination in Dynamic  Procurement Design with Learning-by-doing
% Klenio Barbosa and Pierre Boyer
% November/2016
% Begin: Uniform Distribution
%------------------------------------------------------------------------%
% Uniform Distribution
%% Clearing the workspace
clc;
clear all
%% Creating a symbolic variable
% x would be x with ~
syms c x;
%% Numerical Part
%% Creating vectors of costs
csd=0;
csu=0.1;
cwd=0;
cwu=0.1:100;
lambda=2;
%% Cost of public funds
alpha=1;
%weight of the firms' profit in the Social Welfare Functions

%% Uniform Distribution
%% Cumulative Distribution Function F
%% Probability Density Function  f
FS=(c-csd)/(csu-csd);
fs=1/(csu-csd);

%% Double Integral
%% Solution of Numerical Result 1
```

```
n=numel(cwu);
p1=zeros(n,1);
p2=zeros(n,1);
sol=zeros(n,1);
fw=zeros(n,1);

phis1= simplify(finverse(phisu(c,lambda,alpha,csd)));
phiw1=simplify(finverse(phisu(c,lambda,alpha,cwd)));
phiw_s=simplify(subs(phiw1,c,phisu(c,lambda,alpha,csd)));
phis_w=simplify(subs(phis1,c,phisu(c,lambda,alpha,cwd)));

p=int(c*(1-FS)*fs,c,csd,csu);

for i=1:n
    fw(i)=1./(cwu(i)-cwd);
    p1(i)=int(int(x*fw(i),x,cwd,phiw_s)*fs,csd,csu);
    p2(i)=int(int(x*fs,x,csd,phis_w)*fw(i),c,cwd,cwu(i));
    sol(i)=p-0.5*(p2(i)+p1(i));
end

str2='$$\Delta$$';
str1='$$\overline{c}_{w}$$';
str0='(a) Uniform Distribution';

% Plotting simulations in the graph.
plot(cwu,sol,'-','color','blue','LineWidth',2)
xlabel(str1,'interpreter','latex','fontsize',12)
ylabel(str2,'interpreter','latex','fontsize',12)
title(str0,'interpreter','latex','fontsize',12)
%axis tight
grid on
%-------------------------------------------------------------------------%
% End: Uniform Distribution
%-------------------------------------------------------------------------%


%-------------------------------------------------------------------------%
% Discrimination in Dynamic  Procurement Design with Learning-by-doing
% Klenio Barbosa and Pierre Boyer
% November/2016
% Begin: Pareto Distribution
%-------------------------------------------------------------------------%
clear all;
% Pareto Distribution
%% Clearing the workspace
```

```
clc;

%% Creating symbolic variables
syms c x;

%% Parameters of the Pareto Distribution

%% Parameter that guarantees that the Strong Distribution stocastically dominates
%% the Weak Distribution
% csd=>cwd
% csu<=cwu

%% Strong Distribution
csd=1;
csu=+inf;

%% Weak Distribution
cwd=1:10;
cwu=+inf;
n=numel(cwd);

%% Parameters of the Pareto Distribution
gamma=1;
gamma2=2;

%% Parameters of the Paper
lamda=2;
%cost of public funds
alpha=1;
%weight of the firms' profit in the Social Welfare Functions

% Cumulative Distribution Funcion F
% Probability Density Function  f

%% Preallocating variables
phiw1=sym(zeros(n,1));
phiw12=sym(zeros(n,1));

phiw_s=sym(zeros(n,1));
phis_w=sym(zeros(n,1));

phiw2=sym(zeros(n,1));
phiw_s2=sym(zeros(n,1));
phis_w2=sym(zeros(n,1));
```

```
phis1=finverse(phis(c,gamma,lamda,alpha,csd));
phis2=finverse(phis(c,gamma2,lamda,alpha,csd));

%% For the case of gamma=1
%% truncating of the integral
ctil1=zeros(n,1);
ctil2=zeros(n,1);

%% For the case of gamma=2
%% truncating of the integral
ctil12=zeros(n,1);
ctil22=zeros(n,1);

%% The value of the integrals
p=sym(zeros(n,1)); %left in equation (14)
p1=zeros(n,1); %first part of the right in equantion (14)
p2=zeros(n,1); %second part of the right in equantion (14)
sol=zeros(n,1);%Delta in equation (18)

p12=zeros(n,1); %first part of the right in equantion (14)
p22=zeros(n,1); %second part of the right in equantion (14)
sol2=zeros(n,1);%Delta in equation (18)

%% Distribution Functions
fw=sym(zeros(n,1));
fw2=sym(zeros(n,1));

for i=1:n;
phiw1(i)=finverse(phis(c,gamma,lamda,alpha,cwd(i)));
phis_w(i)=simplify(subs(phis1,c,phis(c,gamma,lamda,alpha,cwd(i))));
phiw_s(i)=simplify(subs(phiw1(i),c,phis(c,gamma,lamda,alpha,csd)));
phiw12(i)=finverse(phis(c,gamma2,lamda,alpha,cwd(i)));
phis_w2(i)=simplify(subs(phis2,c,phis(c,gamma2,lamda,alpha,cwd(i))));
phiw_s2(i)=simplify(subs(phiw12(i),c,phis(c,gamma2,lamda,alpha,csd)));
end;

%% Looping ctil 1 and 2
for j=1:n
ctil1(j)=vpasolve(phiw_s(j) == cwd(j),c);
if (ctil1(j)<0)
      ctil1(j)=ctil1(j)*-1;
end
```

```
if (ctil1(j)<csd)
   ctil1(j) = csd;
end

ctil2(j)=vpasolve(phis_w(j) == csd,c);

 if (ctil2(j)<0)
     ctil2(j)=ctil2(j)*-1;
 end

 if (ctil2(j)<cwd(j))
     ctil2(j)=cwd(j);
 end

ctil12(j)=vpasolve(phiw_s2(j) == cwd(j),c);

if (ctil12(j)<0)
      ctil12(j)=ctil12(j)*-1;
end

if (ctil12(j)<csd)
   ctil12(j) = csd;
end

ctil22(j)=vpasolve(phiw_s2(j) == csd,c);

if (ctil22(j)<0)
     ctil22(j)=ctil22(j)*-1;
 end

if (ctil22(j)<cwd(j))
     ctil22(j)=cwd(j);
end

end


for i=1:n
    %gamma=1
    FS=1-((csd/c)^gamma);
    fs=(gamma*(csd^gamma)/(c^(gamma+1)));
    fw(i)=(gamma*(cwd(i).^gamma)./(c^(gamma+1)));
    p=simplify(int(c*(1-FS)*fs,c,csd,csu));
    p1(i)=simplify(int(int(x*subs(fw(i),c,x),x,cwd(i),phiw_s(i))*fs,c,ctil1(i),csu));
```

```
    p2(i)=simplify(int(int(x*subs(fs,c,x),x,csd,phis_w(i))*fw(i),c,ctil2(i),cwu));
    sol(i)=p-0.5.*(p2(i)+p1(i));

    %gamma=2
    FS2=1-((csd/c)^gamma2);
    fs2=(gamma2*(csd^gamma2)/(c^(gamma2+1)));
    fw2(i)=(gamma2*(cwd(i).^gamma2)./(c^(gamma2+1)));
    pi2=simplify(int(c*(1-FS2)*fs2,c,csd,csu));
    p12(i)=simplify(int(int(x*subs(fw2(i),c,x),x,cwd(i),phiw_s2(i))*fs2,c,ctil12(i),csu));
    p22(i)=simplify(int(int(x*subs(fs2,c,x),x,csd,phis_w2(i))*fw2(i),c,ctil22(i),cwu));
    sol2(i)=pi2-0.5.*(p22(i)+p12(i));
end

cwg=1:10:100;
str2='$$\Delta$$';
str1='$$\underline{c}_{w}$$';
str0='(b) Pareto Distribution';

% Plotting simulations in the graph.
plot(cwg,sol,'-','color','blue','LineWidth',2)
xlabel(str1,'interpreter','latex','fontsize',12)
ylabel(str2,'interpreter','latex','fontsize',12)
title(str0,'interpreter','latex','fontsize',12)
%axis tight
grid on
hold on

plot(cwg,sol2,'--','color','red','LineWidth',2)
legend('\gamma=1','\gamma=2')
%------------------------------------------------------------------------%
% End: Pareto Distribution
%------------------------------------------------------------------------%
```
∎

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