No. 2270

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**TRANSITION ECONOMICS**

Centre for Economic Policy Research

*ISSN 0265-8003*

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Discussion Paper No. 2270
October 1999

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CEPR Discussion Paper No. 2270

October 1999

## ABSTRACT

# Procurement Favouritism and Technology Adoption*

The design of cost minimizing procurement rules for the selection of contractors among distinct technological groups requires the favouritism of inefficient firms. It is unclear whether these policies provide incentives for inefficient firms to adopt more efficient technologies. In this paper the inefficient firm may adopt the efficient technology at some cost. Government policy can be effective for an intermediate range of adoption costs. To induce adoption, the government should commit to favour the (initially) inefficient firm, despite both firms eventually having the same technology. Even with limited government commitment, optimal favouritism provides more incentives for technology adoption than a symmetric mechanism.

JEL Classification: D44, F13, H57, O33
Keywords: procurement, protection, technology adoption, auctions

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* Special thanks are due to two anonymous referees, who provided detailed comments that substantially benefited the paper. I am also grateful to Pedro Barros, Roberto Burguet, Luis Cabral, Hugo Hopenhayn, Xavier Martinez, David Perez-Castrillo, Patrick Rey, Michael Riordan, Diego Rodriguez, Klaus Schmidt, Monika Schnitzer, and Jean Tirole for conversations and comments on earlier drafts. This work was mostly done while I was affiliated with the Banco de Portugal. Previous versions of the paper were presented in the CEPR European Summer Symposium in Economic Theory, the EARIE conference, the ASSET meeting, and seminars at the CEMFI, European University Institute, Universidade Catolica Portuguesa, Lisboa, and Universitat

Pompeu Fabra. I thank the hospitality of the Universitat Autonoma de Barcelona, where this research was started. Financial support from the Commission of the European Communities, under the Human Capital and Mobility Program (grant ERBCHBGCT920147) is gratefully acknowledged. Remaining errors are my own.

Submitted 3 August 1999

# NON-TECHNICAL SUMMARY

Public procurement has long been a main area of discrimination between domestic and foreign firms. The issue has been a major concern at the World Trade Organization. The Agreement on Government Procurement was an important chapter in the Uruguay round. The countries approved a principle of non-discrimination, while allowing for a differential treatment of the least developed countries.

The economics literature has provided some useful results regarding this issue. Auction theory has shown that, if the firms have different (ex-ante) efficiencies, the government may gain from discriminating in favour of the inefficient firms, in the sense that it will sometimes be selected even if it does not reveal the lowest cost. By doing that, the government increases the competitive pressure on the efficient firms. In trading-off the two effects the government reduces the expected procurement cost by imposing some degree of discrimination. This result has been used to understand government discrimination in favour of domestic (inefficient) firms relative to foreign (efficient) firms. But these are static arguments. They do not discuss the (possibly perverse) incentives that the protectionism of inefficient firms may have on their incentives for the adoption of more efficient technologies. The objective of the present paper is to address this concern.

This paper considers a model where an inefficient firm must decide whether or not to adopt cost reducing technologies. The main conclusion is that the favouritism of inefficient firms promotes the adoption. Protection of the inefficient firms increases not only the firms' expected rents, but also the firms' gross benefits from the adoption of a more efficient technology. Therefore, the optimal procurement policy discriminates in favour of the (initially) inefficient firms.

One interesting issue is to compare the equilibrium adoption rules in the paper with the social welfare maximizing adoption rule under complete information. To maximize the social welfare under complete information, adoption should take place whenever the adoption cost is lower than the expected reduction in the firms' minimum cost, and the government should select the firm with the lowest cost. The government's costs and benefits from the adoption under incomplete information differ from those of the social planner under complete information. The government induces adoption by distorting the selection probabilities in favour of the inefficient firms. Inducing the adoption has a cost, as it increases the rents of inefficient firms. However, it also generates benefits, in that it limits the rents of the efficient firms and it reduces the expected minimum cost. The Paper shows that the government

overinternalizes the effects of adoption and that there is over-adoption compared to the first best under complete information.

The issue of commitment is central to any discussion of favouritism in auctions. It is particularly relevant when the concern is with long-term effects. In this paper, two versions of the model, with varying degrees of government commitment, are considered. The conclusion that favouritism may help adoption is robust to changes on the degree of government commitment.

The paper discusses the protection of inefficient firms. It is useful for industrial policy, in general. Even though it is not framed in terms of domestic and foreign firms, the conclusions highlight some issues that are relevant to the discussion about the protection of domestic firms in public procurement. Nevertheless, the analysis is developed within a simple theoretical model so the conclusions should not be read as a complete argument for fine-tuned protection policies: that would certainly require a much more general analysis.

# 1 Introduction

Public procurement has long been a main area of discrimination between domestic and foreign firms.[1] Many countries have (explicitly or implicitly) implemented clauses that favor domestic firms. The issue has been a major concern to the WTO. The Agreement on Government Procurement was an important chapter in the Uruguay round. The countries approved a principle of non-discrimination, while allowing for a differential treatment of the least developed countries.

The economics literature has provided some useful results to think about this issue. The basic problem is that of an agent who wants to buy a good from one of two potential sellers (firms 1 and 2), with unknown costs. Auction theory (Myerson, 1981) has shown that, if the firms have different (*ex-ante*) efficiencies, the buyer may gain from discriminating in favor of the inefficient seller, in the sense that it will sometimes be selected even if it does not reveal the lowest cost. McAfee and McMillan (1989) used this result to understand government's discrimination in favor of domestic (inefficient) firms relative to foreign (efficient) firms.[2]

But, those are static arguments. They do not discuss the (possibly perverse) incentives that the protectionism of inefficient firms may have on their incentives for the adoption of more efficient technologies. The objective of the present paper is to address this concern. I consider a model where an inefficient firm must decide whether or not to adopt cost reducing technologies. The main conclusion is that the favoritism of inefficient firms promotes the adoption.[3] Protection increases not only the firms' expected rents, but also the firms' gross benefits from the adoption of a more efficient technology. Therefore, unless the cost of adopting the efficient technology is low, the optimal procurement policy discriminates in favor of the (initially) inefficient firms.

The issue of commitment is central to any discussion of favoritism in auctions. It is particularly relevant when one is concerned with long term effects. I consider two versions of the model

[1] This has extensively been documented in McAfee and McMillan (1989), WS Atkins Management Consultants et al. (1988), and Commission of the European Communities (1992).

[2] Other papers have addressed this problem from alternative perspectives. A general preference for domestic firms can easily be rationalized if the government has better means to receive side transfers from the domestic firms than from the foreign firms (Laffont and Tirole, 1991), or if the government cares about domestic welfare, which includes domestic firms' profits but not foreign firms' profits (Branco, 1994, and Vagstad, 1995).

[3] In a recent paper, Naegelen and Mougeot (1998) developed a model with a similar concern but taking a different approach. It is a model in the spirit of Laffont and Tirole (1987), in which the firms can reduce their cost through a non-observable effort. They show that cost reduction concerns are not relevant for the determination of the selection rule. This is so because the government has an additional instrument (the cost target imposed on the contractor) which is used to induce cost reduction.

with varying degrees of government's commitment.[4] The conclusion that favoritism may help the adoption does not depend on the degree of government's commitment.[5]

The model discusses the protection of inefficient firms. It is useful for industrial policy, in general. Even though, it is not framed in terms of domestic and foreign firms, the conclusions highlight some issues that are relevant to the discussion about the protection of domestic firms in public procurement. Nevertheless, the analysis is developed within a simple theoretical model. So, the conclusions should not be read as a complete argument for fine-tuned protection policies. That would certainly require a much general analysis.

The structure of the paper is the following. In the next section I present the model, which generalizes the environment considered in McAfee and McMillan (1989). Section 3 derives the optimal mechanism under government's full commitment. I show how favoring the inefficient firms creates an incentive for their adoption of the efficient technology. A similar analysis is carried out in Section 4 for the government's limited commitment case. Section 5 concludes. The proofs and some examples are provided in the appendices.

## 2 Modeling Issues

I extend the model used in McAfee and McMillan (1989) to allow for the possibility of technology adoption. There are three risk neutral agents: the government and two firms (firms 1 and 2).[6] There is a single representative public project to be completed regardless of the firms' efficiencies, because it generates a very large increase in the consumer surplus. The government is interested in designing an auction to select the firm that will carry out the project in a way that minimizes its expected procurement expenditure.[7]

Two technologies are available: technology $H$ and technology $L$. The costs of the firms are independently determined according to the technology used. A firm with technology $j$ ($j \in \{L, H\}$) will have a cost distributed on the interval $[\underline{c}, \bar{c}]$, according to a positive density $g^j(\cdot)$ and cumulative

[4] I am grateful to a referee that suggested me this approach.

[5] The government needs only be committed to a mechanism when bids are to be submitted.

[6] The restriction to two firms is a simplification and the model easily generalizes to a larger number of firms, with no qualitative impact on the conclusions.

[7] Which, in this model, is the same as the maximization of expected welfare.

distribution function $G^j(\cdot)$. The distribution $G^H(\cdot)$ first order stochastically dominates $G^L(\cdot)$.[8] In this sense, I say that technology $L$ is more efficient than technology $H$. I assume that both distribution functions are log-concave.

The firms are *ex-ante* different. Firm 1 is endowed with technology $H$ while firm 2 is endowed with technology $L$. Before bidding for the project, firm 1 may, at cost $K$, adopt the efficient technology.

The objective of the analysis is the identification of the optimal auction, under these circumstances. A fundamental assumption is that the government does not observe firm 1's technology choice. Therefore, the rules of the mechanism for the selection of the contractor can not be contingent on the technology of firm 1. This prevents the use of direct subsidies to the adoption of the efficient technology, which would otherwise trivially solve the problem. Hence, the government may only select a contractor on the basis of the costs reported at the auction.

As a modeling device I use two alternative extensive form games. In the first extensive form, which I refer to as the full commitment case, the government starts by deciding and announcing the rules for awarding the contract, i.e., how will the winning firm be selected and payments be determined. In a second stage, firm 1, knowing the auction rules, has an opportunity to adopt technology $L$, provided it makes a fixed payment of $K$. Finally, in a third stage, each firm privately learns its true cost for fulfilling the contract and makes a report to the government, who then awards the contract according to the rules previously specified; payments take place, and payoffs are realized. The timing of this game is depicted in Figure 1.

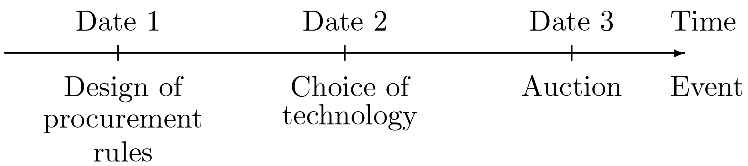


Figure 1: Full commitment case: Timing of the decisions.

The second extensive form game corresponds to the limited commitment case. Then, firm 1's adoption decision and the design of the auction rules are simultaneous. The timing of the second extensive form game is represented in Figure 2.

[8]This means that it is more likely for a firm using technology $L$ to have a cost lower than $c \in (\underline{c}, \bar{c})$ than for a firm using technology $H$, i.e., $G^L(c) > G^H(c)$, for $c \in (\underline{c}, \bar{c})$. The properties of functions throughout the paper will always be done for $c \in (\underline{c}, \bar{c})$, unless something else is explicitly stated.

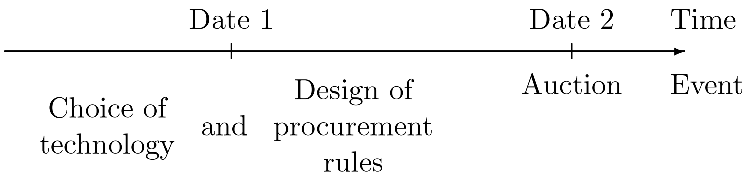

Figure 2: Limited commitment case: Timing of the decisions.

The analysis is carried out by computing perfect Bayesian equilibria in each extensive form game. The case of full commitment is studied in the next section, followed by the limited commitment case in Section 4.

# 3 The Optimal Mechanism under Full Commitment

The government wants to set up a mechanism that minimizes its expected procurement cost, without observing the firm's costs nor the technology chosen by firm 1. I use the Revelation Principle (Myerson, 1979) to work with revelation mechanisms, that specify selection probabilities $(p_1, p_2)$ and expected payments $(t_1, t_2)$ as functions of the firms' reported costs. In the analysis I will focus on the selection probabilities and the on firm 1's equilibrium choice of technology.

Given a mechanism, we may compute the profit of firm 1 before it chooses its technology (*ex-ante* profit, denoted by $\Pi_1^j$, with $j \in \{L, H\}$) or after firm 1 knows its cost and before the auction takes place (*interim* profit, denoted by $\pi_1(c_1)$). These profits are given by:[9]

$$\pi_1(c_1) \equiv t_1(c_1) - c_1 \, \mathrm{E}_{G^L}\{p_1(c_1, c_2)\} \tag{1}$$

$$\Pi_1^j \equiv \mathrm{E}_{G^j}\{\pi_1(c_1)\} - K\, I(j)\,,\ j \in \{L, H\}\,, \tag{2}$$

where $I(H) = 0$ and $I(L) = 1$, and the expectation in (1) is computed relative to firm 2's cost.[10] Firm 1 will choose its technology at the *ex-ante* level. In equilibrium, it will adopt technology $L$, if and only if $\Pi_1^L \geq \Pi_1^H$.[11]

The government will infer the equilibrium behavior of firm 1. It will commit to a selection mechanism that minimizes its expected cost: $\mathrm{E}_{G^j}\{t_1(c_1)\} + \mathrm{E}_{G^L}\{t_2(c_2)\}$ where $j$ ($j \in \{L, H\}$) is

[9] I will use the notation $\mathrm{E}_{G^j}\{\cdot\}$ when the expectation is computed under the distribution function of technology $j$.

[10] Usually I will omit the reference to the variable whose expectation is computed. That should be clear from the arguments of the functions.

[11] I assume that in the case of indifference, firm 1 will adopt technology $L$.

the technology chosen in equilibrium by firm 1.

A solution to the government's problem is obtained in two steps.[12] In the first step, I construct the minimum cost mechanisms to induce firm 1 to use either technology. In the second step, I compare the costs of those mechanisms. The government should then implement the less expensive mechanism of the two.

The minimum cost mechanism to induce firm 1 to keep technology $H$ solves a minimization problem subject to the standard *interim* incentive compatibility, individual rationality and feasibility constraints, expanded with the no-adoption constraint, $\Pi_1^H \geq \Pi_1^L$. The latter ensures firm 1's incentive compatibility when choosing its technology. This seems to be a complicated problem. However, if it is optimal for the government that firm 1 keeps technology $H$, the no-adoption constraint will not be binding.[13] So, there is no loss of generality in ignoring the no-adoption constraint in this analysis. The problem is then the same as in McAfee and McMillan (1989).

Define the functions:

$$J^j(c) \equiv c + \frac{G^j(c)}{g^j(c)}\,, \tag{3}$$

which are the expected costs to the government of selecting a firm that drew cost $c$ from technology $j$ ($j \in \{L, H\}$). These are referred to as the virtual costs. Due to the asymmetry of information, the selected firm is able to extract from the government a payment that exceeds its true cost. It gets an informational rent. The second term in (3) measures the firm's informational rent.

From the log-concavity of the distribution functions, the virtual costs are increasing functions. Hence, I may define $z^H(c)$ as:

$$z^H(c) = J^{H^{-1}}(J^L(c))\,. \tag{4}$$

The minimum cost mechanism is described in the following proposition (McAfee and McMillan, 1989, Theorem 1).

[12]The approach is similar to the two step procedure in Grossman and Hart (1983) for the identification of the optimal incentive scheme in a moral hazard framework.

[13]Suppose that, to induce firm 1 to keep technology $H$, the no-adoption constraint is binding. Consider now the relaxed problem, without the no-adoption constraint. If the government changes to the optimal mechanism in the relaxed problem there will be two effects on the expected procurement cost: a direct effect, which reduces the expected procurement cost even if firm 1 were to keep technology $H$; and an indirect effect, which further reduces the expected procurement cost because firm 1 will change to technology $L$. Hence, in such a situation, it is not optimal for the government that firm 1 keeps technology $H$.

**Proposition 1** *Suppose that the government wants firm 1 to use technology $H$. This is done at minimum expected cost by selecting firm 1 if and only if $c_1 \leq z^H(c_2)$.*

I will refer to the mechanism that achieves the minimum expected cost as the minimum cost no-adoption mechanism. I will denote the probability that firm $i$ ($i \in \{1, 2\}$) is selected under this mechanism when costs are $c_1$ and $c_2$ by $p_i^H(c_1, c_2)$.

Some of the discussion throughout the paper is about favoritism of firm 1. Given a mechanism, I will say that it favors firm 1, if the highest cost that leads to the selection of firm 1 exceeds firm 2's cost. Thus, the minimum cost no-adoption mechanism favors firm 1 if $z^H(c_1) > c_1$. This holds if and only if $G^H(c)/G^L(c)$ is increasing in $c$ (McAfee and McMillan, 1989, Theorem 3).

The situation becomes more complex if the government wants to induce firm 1 to adopt technology $L$. Now the mechanism must be designed to take into consideration the adoption constraint, $\Pi_1^L \geq \Pi_1^H$, that can not in general be relaxed.[14]

I introduce a new function:

$$\tilde{J}(c; \lambda) \equiv c + \frac{G^L(c)}{g^L(c)} - \lambda \frac{G^L(c) - G^H(c)}{g^L(c)}, \tag{5}$$

where $\lambda$ is the multiplier of the adoption constraint in the government's minimization problem. The function $\tilde{J}(\cdot; \lambda)$ is the adjusted virtual cost of selecting firm 1, after technology $L$ has been adopted. If the adoption constraint is not binding, $\lambda = 0$ and $\tilde{J}(c; 0) = J^L(c)$. Otherwise, $\lambda > 0$ and $\tilde{J}(c; \lambda) < J^L(c)$.

The expression of $\tilde{J}(\cdot; \lambda)$ can be understood in the following way. The first two terms in (5) are the virtual cost of firm 1 if it adopts technology $L$ without requiring any distortion in the selection mechanism. If the adoption constraint is binding, the government will distort the selection rules to provide an increase in firm 1's (gross) informational rents and induce the firm to adopt. But not all the (gross) informational rents will be devoted to the payment of the adoption cost. Only those in excess of the rents that the firm could retain by exercising its option of not to adopt, i.e., $G^L(\cdot) - G^H(\cdot)$. The (marginal) value of these rents to the government is $\lambda \left( G^L(\cdot) - G^H(\cdot) \right)$. This

[14] There are values of $K$ for which it is impossible to satisfy the adoption constraint. Nevertheless, it is shown in the Appendix that this does not limit our ability to address the main question. For the relevant range of the parameter values the problem does not exist.

term must then be reduced from the virtual cost to get the appropriate measure of the government's cost from selecting firm 1.

The adjusted virtual cost need not be an increasing function. A full analysis of the problem would then involve the consideration of two cases: the regular case, if $\tilde{J}(\cdot;\lambda)$ is increasing; and the non-regular case, otherwise. The solution to the regular case is easy to identify. To the contrary, to solve the problem in the non-regular case one must apply a standard ironing procedure used to characterize non-regular optimal auctions (see, for example, Myerson, 1981). This greatly increases the technical difficulties of the analysis without adding much to our understanding of the problem. For example, the basic properties of the optimal selection mechanisms, such as those related to the discrimination between the firms, are similar in the regular and non-regular cases. Hence, to focus on the essential results, I have limited the analysis in this section to the regular case.[15] In this case I may define $\tilde{z}(c;\lambda)$ as:

$$\tilde{z}(c;\lambda) = \tilde{J}^{-1}(J^L(c)). \tag{6}$$

**Proposition 2** *Suppose that the government wants to induce firm 1 to adopt technology $L$. This is done at minimum expected cost by selecting firm 1 if and only if $c_1 \leq \tilde{z}(c_2;\lambda)$.*

The proposition covers two cases. If adoption is not too costly, the adoption constraint will not be binding, so $\lambda = 0$ and $\tilde{z}(c;\lambda) = c$. The two firms will be equally treated, with the lowest cost firm being selected. Firm 1 adopts technology $L$, paying $K$ out of its informational rents. On the contrary, if adoption is sufficiently expensive, the constraint will be binding and $\lambda > 0$. The optimal mechanism will then differentiate the two firms. The bias introduced is characterized in the following proposition.

**Proposition 3** *If the adoption constraint is binding, the mechanism that induces the adoption of technology $L$ at minimum expected cost favors firm 1.*

The need for favoritism of firm 1 is general and, unlike the minimum cost no-adoption mechanism, it does not rely on any further assumption. This is so because, if the adoption constraint is binding, firm 1 can only be induced to adopt technology $L$ if its informational rents (gross of the

[15] An example of the non-regular case is solved in the Appendix.

adoption cost) are increased non-uniformly over types. To achieve this target, and given its lack of information, the government must bias the selection rule towards firm 1.

I may now move to the description of the overall optimal decision, which is done in reference to the level of the adoption cost.

**Proposition 4** *There exist values* $\tilde{K}^L$ *and* $\tilde{K}^H$*, with* $0 < \tilde{K}^L < \tilde{K}^H$*, such that the minimum expected cost mechanism has the following properties:*

1. *If* $K \leq \tilde{K}^L$*, the government will select firm 1 if and only if* $c_1 \leq c_2$*, and the latter adopts technology* $L$*;*

2. *If* $\tilde{K}^L < K \leq \tilde{K}^H$*, the government will select firm 1 if and only if* $c_1 \leq \tilde{z}(c_2; \lambda)$*, inducing it to adopt technology* $L$*;*

3. *If* $K > \tilde{K}^H$*, the government will select firm 1 if and only if* $c_1 \leq z^H(c_2)$*, and the latter keeps technology* $H$*.*

The result in the proposition is summarized in Figure 3. At low adoption costs, the firm with the lowest production cost is selected. At intermediate adoption costs there is favoritism of firm 1, which induces adoption of the low cost technology. At high adoption costs, firm 1 keeps technology $H$, possibly being favored.

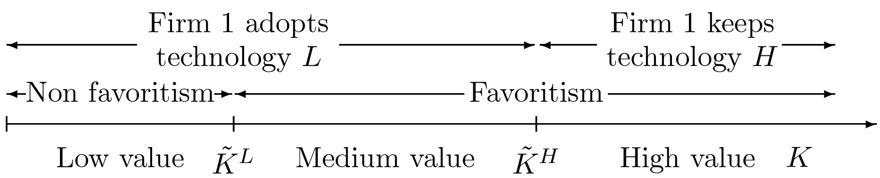


Figure 3: Equilibrium behavior.

One interesting issue is to compare the equilibrium adoption rule in this model with the social welfare maximizing adoption rule under complete information.

**Proposition 5** *Under complete information, social welfare would be maximized when adoption would take place if and only if* $K \leq \tilde{K}^L$*.*

To maximize the social welfare under complete information, firm 1 should adopt technology $L$ whenever the adoption cost is lower than the expected reduction in the minimum cost, and the government should select the firm with the lowest cost. Under incomplete information, if the adoption constraint is not binding, the government will select the firm with the lowest cost, and the benefit of firm 1 from adoption is exactly equal to the reduction in the expected minimum cost. Firm 1 has the same incentives to adopt, under these circumstances, as the social planner in the complete information case.

The government's costs and benefits from firm 1's adoption under incomplete information differ from those of the social planner under complete information. Under incomplete information, the government induces adoption by distorting the selection probabilities in favor of firm 1. Inducing the adoption has a cost: it increases firm 1's informational rents. But it also generates benefits: it limits firm 2's informational rents and it reduces the expected minimum cost. When $K$ is slightly above $\tilde{K}^L$ the cost is negligible while the benefits are bounded away from zero. So the government overinternalizes the effects of adoption and there is over-adoption compared to the first best under complete information.[16]

## 4 The Optimal Mechanism under Limited Commitment

The optimal mechanism described in the previous section relies on the assumption that the government commits to the selection rules before firm 1 chooses its technology. However, when the adoption must be induced, the government's commitment becomes a major issue. Even though the firms will *ex-post* be technologically identical, and (in equilibrium) everyone will know it, the government should discriminate in favor of firm 1. Under limited commitment this mechanism will not be possible. Just after firm 1 had chosen its technology (having adopted the low cost one), the government would change the rules. It would want to select the lowest cost firm. Anticipating this behavior, firm 1 would not adopt the efficient technology. In this section, I analyze the problem when the government has limited commitment only. This is modelled by assuming that the government's design of the procurement rules and firm 1's choice of technology are done simultaneously.

To compute the equilibrium with government's limited commitment, I describe first the be-

[16]Similar effects have been detected in adverse selection models where the distortion in other variables may by used to limit informational rents (McAfee and McMillan, 1986; Laffont and Tirole, 1987; Riordan and Sappington, 1987; Che, 1993).

havior of the government. Let $\theta$ be the probability that firm 1 keeps technology $H$ and $\hat{\theta}$ be the government's belief about that probability. Then, from the point of view of the government, firm 1 will draw its cost from a cumulative distribution function $(1-\hat{\theta})G^L(\cdot)+\hat{\theta}G^H(\cdot)$. Let the (believed) virtual cost of firm 1 be denote by $\hat{J}(c;\hat{\theta})$, i.e.:

$$\hat{J}(c;\hat{\theta}) = c + \frac{(1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)}{(1-\hat{\theta})g^L(c)+\hat{\theta}g^H(c)}\,.$$

This function is continuous, satisfying $\hat{J}(c;0) = J^L(c)$ and $\hat{J}(c;1) = J^H(c)$. Moreover, I assume that it is an increasing function of $c$. Hence, I define the function $\hat{z}(c;\hat{\theta})$ as:

$$\hat{z}(c;\hat{\theta}) = \begin{cases} \bar{c} & \text{if } \hat{J}(\bar{c};\hat{\theta}) < J^L(c), \\ \hat{J}^{-1}(J^L(c);\hat{\theta}) & \text{otherwise.} \end{cases} \tag{7}$$

**Proposition 6** *If the government believes that firm 1 keeps technology $H$ with probability $\hat{\theta}$, its best reply will be to select firm 1 if and only if $c_1 \leq \hat{z}(c_2;\hat{\theta})$.*

This proposition describes a family of government's best reply mechanisms, indexed by the belief $\hat{\theta}$. When $\hat{\theta}$ equals 0, it corresponds to a symmetric auction, the optimal one given that both firms have the same technology. When $\hat{\theta}$ equals 1, it corresponds to the optimal auction when it is known that firm 1 has kept technology $H$. Some properties of the family of best reply mechanisms are provided in the lemmas that follow.

**Lemma 1** *The government's best reply to $\hat{\theta} > 0$ will favor firm 1 if and only if $G^H(c)/G^L(c)$ is increasing in $c$.*

This lemma generalizes Theorem 3 in McAfee and McMillan (1989). The condition for favoritism of firm 1 is unchanged as long as firm 1 is believed to keep technology $H$ with positive probability. The remaining of the analysis is done under the assumption that the condition in Lemma 1 is satisfied, so that the government's best reply mechanisms favor firm 1.

The government's best reply to $\hat{\theta}_1$ favors firm 1 more than its best reply to $\hat{\theta}_0$ if $\hat{z}(c_2;\hat{\theta}_1) > \hat{z}(c_2;\hat{\theta}_0)$.

**Lemma 2** *Given $\hat{\theta}_0$ and $\hat{\theta}_1$ in $[0,1]$, the government's best reply to $\hat{\theta}_1$ favors firm 1 more than its best reply to $\hat{\theta}_0$ if and only if $\hat{\theta}_1 > \hat{\theta}_0$.*

**Lemma 3** *Given $\hat{\theta}_0$ and $\hat{\theta}_1$ in $[0,1]$, firm 1's (gross) benefit from the adoption of technology L is larger when facing the government's best reply to $\hat{\theta}_1$ than when facing the government's best reply to $\hat{\theta}_0$ if and only if $\hat{\theta}_1 > \hat{\theta}_0$.*

McAfee and McMillan (1989) characterized the optimal mechanism when technology adoption is not possible. The starting point for this paper was to study whether the optimal favoritism of an inefficient firm would erode its incentives to become more efficient. Lemma 3 shows that, to the contrary, among the government's best reply mechanisms the minimum cost no-adoption mechanism is the one that provides the largest incentives for firm 1 to adopt more efficient technologies.

Let me now turn to firm 1's behavior. Suppose that the government is playing a best reply to $\hat{\theta}$. Let $\hat{\kappa}(\hat{\theta})$ be the largest adoption cost that firm 1 is willing to pay, given that mechanism, i.e.,[17]

$$\hat{\kappa}(\hat{\theta}) = \int_{\underline{c}}^{\bar{c}} \left(1 - G^L(\hat{z}^{-1}(c_1;\hat{\theta}))\right) \left(G^L(c_1) - G^H(c_1)\right) dc_1 \,.$$

From Lemma 3, $\hat{\kappa}(\cdot)$ is an increasing (continuous) function. The best reply (correspondence) of firm 1 is then given by:

$$\vartheta(\hat{\theta};K) = \begin{cases} \{0\} & \text{if } K < \hat{\kappa}(\hat{\theta}) \\ [0,1] & \text{if } K = \hat{\kappa}(\hat{\theta}) \\ \{1\} & \text{if } K > \hat{\kappa}(\hat{\theta}) \end{cases} .$$

It follows that, for any $K > 0$, $\vartheta(\cdot;K)$ has a unique fixed point. Therefore, there is a unique equilibrium that is characterized in the following proposition.

**Proposition 7** *There exist values $\hat{K}^L$ and $\hat{K}^H$, with $0 < \hat{K}^L < \hat{K}^H$, such that, in equilibrium:*

1. *If $K \leq \hat{K}^L$, firm 1 will adopt technology L with probability 1 and the government will select it if and only if $c_1 \leq c_2$;*

2. *If $\hat{K}^L < K \leq \hat{K}^H$, firm 1 will keep technology H with probability $\theta \in \vartheta(\theta;K)$, and the government will select it if and only if $c_1 \leq \hat{z}(c_2;\theta)$;*

3. *If $K > \hat{K}^H$, firm 1 will keep technology H with probability 1, and the government will select it if and only if $c_1 \leq z^H(c_2)$.*

[17] The expression for $\hat{\kappa}(\hat{\theta})$ can be obtained replicating the steps for the identification of $\tilde{K}^L$ and $\tilde{K}^H$ in the proof of Proposition 4.

The main conclusion drawn from this analysis is that, even constraining the government's to limited commitment, the optimal favoritism of firm 1 does not eliminate the incentives for technology adoption. To the contrary, it may promote the adoption of the low cost technology.

From the proofs of Propositions 4 and 7, it follows that $\tilde{K}^L = \hat{K}^L$ and $\tilde{K}^H \geq \hat{K}^H$. So, like in the case of government's full commitment, there is over-adoption compared to the complete information first best. However, the excessive adoption is now lower than under government's full commitment, because $\tilde{K}^H \geq \hat{K}^H$ and the adoption probability is now less than 1 for $K \in (\hat{K}^L, \hat{K}^H)$.

## 5 Concluding Remarks

There have been some papers providing arguments to rationalize the widespread favoritism of domestic firms in procurement contracts. A key argument has been to show that governments may gain from protecting inefficient domestic firms, because that puts competitive pressure on efficient foreign firms, reducing the government's procurement cost. That argument has however been developed in a short term perspective. One may wonder whether by protecting inefficient firms the government will erode their incentives to adopt more efficient technologies. If so, a favoritism policy could be harmful in the long term.

In this paper, I looked at a model in which the decision of technology adoption by an inefficient firm is explicitly considered. The conclusions were the following. If the cost of switching to the new technology is sufficiently low, compared to the increase in the firms' profits, the arguments for favoring the inefficient firms in the allocation of contracts are lost; indeed the government should optimally commit not to discriminate in favor of the inefficient firms, pressuring them to become more efficient. On the other hand, if the adoption cost is sufficiently high, relative to the firms' profits, the inefficient firms will not have the financial capacity to adopt, even though it would be in the government's interest that they do so. In this case, the government should discriminate in favor of the inefficient firms, letting them internalize some of the benefits of technology adoption.

The previous situation raises some commitment issues. The government would have to favor some firms, while at the time of the auction all of them would be drawing their costs from the same technology. Even assuming that the government can not commit to such a strategy, I showed that the incentives for technology adoption are optimally provided by favoring the inefficient firms.

The analysis also showed that there will be over-adoption, relative to the full information first best. The government uses this distortion to limit the firms' informational rents, and thus the expected procurement cost. This result relates to conclusions in several papers that show that the principal may limit the expected procurement cost under incomplete information imposing some distortion on other variables that are relevant for the fulfillment of the contract.

This paper is a first step towards a more complete analysis of the long run impacts of discriminatory practices in procurement. It opens up the possibility of additional research. For example, a more general model could allow for the possibility that neither of the firms starts with the efficient technology, and both could, at some cost, adopt a more efficient technology. Then, the government will have to balance the benefits of favoring either firm. Which firm will the government favor in such a setting? Will the government want to favor the least efficient firm, so that over time, firms alternate in implementing the leading technology? Or, to the contrary, will the government want to promote technological asymmetry? The results in this and past papers seem to suggest that the government ought to favor the least efficient firm. But, being at a competitive disadvantage, the incentives for this firm to voluntarily adopt the most efficient technology are greater than those for the leading firm. Hence, there may be some need to favor the technologically most advanced firm. It is unclear which effect will dominate.

# Appendix A Proofs

## A1 Proof that optimal adoption may be induced in the full commitment case

The adoption constraint under full commitment can be written in the following way:

$$\mathrm{E}_{G^L}\left\{\int_{c_1}^{\bar{c}} P_1(x)\,dx\right\} - \mathrm{E}_{G^H}\left\{\int_{c_1}^{\bar{c}} P_1(x)\,dx\right\} = \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^H(c_1)\right) P_1(c_1)\,dc_1 \geq K\,. \tag{A1}$$

From the assumption that $G^H(\cdot)$ first order stochastically dominates $G^L(\cdot)$ it follows that the left hand side of (A1) is maximized if $P_1(c_1) = 1$, for all $c_1$. Thus, the maximum cost of adoption for which the government may still induce firm 1 to adopt is given by $\int_{\underline{c}}^{\bar{c}}(G^L(c_1) - G^H(c_1))dc_1$. Using such a selection rule implies an expected procurement cost equal to $\bar{c}$. This is larger than the minimum expected procurement cost if technology $L$ is not adopted. Hence, given that the expected cost of implementing $L$ is continuous and increasing in $K$, one concludes that the adoption constraint can be satisfied for adoption costs for which the government may optimally want to induce firm 1 to adopt technology $L$.

## A2 Proof of Proposition 2

The problem of a fully committed government that wants to induce firm 1 to adopt can be written as:

$$\min_{\{p_1,p_2,\lambda\}} \quad \mathrm{E}_{G^L\times G^L}\left\{\tilde{J}(c_1;\lambda)\,p_1(c_1,c_2)+J^L(c_2)\,p_2(c_1,c_2)\right\}+\lambda\,K$$

$$\text{s.t.}\quad \begin{cases} (c_i-c_i')\ (P_i(c_i)-P_i(c_i'))\leq 0 \\ p_1(c_1,c_2)+p_2(c_1,c_2)=1 \\ p_i(c_1,c_2)\geq 0 \\ \lambda\geq 0 \end{cases} \qquad i=1,2\,. \tag{$\mathcal{P}1$}$$

Ignoring the monotonicity constraints on $P_i(c_i)$, Problem ($\mathcal{P}1$) is linear in the selection probabilities, $p_i(\cdot,\cdot)$. Thus the selection rules:

$$\tilde{p}_1(c_1,c_2;\lambda)=\begin{cases} 1 & \text{if } \tilde{J}(c_1;\lambda)\leq J^L(c_2) \\ 0 & \text{otherwise.} \end{cases} \tag{A2}$$

$$\tilde{p}_2(c_1,c_2;\lambda)=1-\tilde{p}_1(c_1,c_2;\lambda)\,, \tag{A3}$$

are (part of) the solution to the problem. From the fact that $\tilde{J}(\cdot;\lambda)$ and $J^L(\cdot)$ are increasing functions, these selection rules satisfy the monotonicity constraints. Moreover, $\tilde{J}(c_1;\lambda)\leq J^L(c_2)\Leftrightarrow c_1\leq\tilde{z}(c_2;\lambda)$ Finally, $\lambda$ is determined through the complementary slackness conditions:[18]

$$\lambda\left(K-\int_{\underline{c}}^{\bar{c}}\left(G^L(c_1)-G^H(c_1)\right)\tilde{P}_1(c_1;\lambda)\,dc_1\right)=0 \tag{A4}$$

$$\int_{\underline{c}}^{\bar{c}}\left(G^L(c_1)-G^H(c_1)\right)\tilde{P}_1(c_1;\lambda)\,dc_1\geq K \tag{A5}$$

$$\lambda\geq 0\,. \tag{A6}$$

[18] I use $\tilde{P}_1(c_1;\lambda)$ to denote $\mathrm{E}_{G^L}\{\tilde{p}_1(c_1,c_2;\lambda)\}$.

## A3 Proof of Proposition 3

Under the regularity assumption, favoritism of firm 1 implies $\tilde{J}(c;\lambda) < J^L(c)$. This condition can be written as $\lambda\left(G^L(c) - G^H(c)\right) > 0$, which holds because $\lambda > 0$ and $G^H(c)$ first order stochastically dominates $G^L(c)$.

## A4 Proof of Proposition 4

Take $\tilde{P}_1(c_1;\lambda)$ as defined in the proof of Proposition 2. Let $\tilde{\kappa}(\lambda)$ be the largest adoption cost that firm 1 is willing to pay, given that mechanism:

$$\begin{aligned}\tilde{\kappa}(\lambda) &= \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^H(c_1)\right) \tilde{P}_1(c_1;\lambda)\, dc_1 \\ &= \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^H(c_1)\right) \left(1 - G^L(\tilde{z}^{-1}(c_1;\lambda))\right) dc_1\,. \end{aligned} \tag{A7}$$

$\tilde{K}^L$ results from (A7) when $\lambda = 0$; then $\tilde{z}^{-1}(c_1;\lambda) = c_1$ and:

$$\tilde{K}^L = \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^H(c_1)\right) \left(1 - G^L(c_1)\right) dc_1\,. \tag{A8}$$

Let $\lambda^H$ satisfy the following condition:[19]

$$\mathrm{E}_{G^L\times G^L}\left\{\sum_{i=1}^{2} J^L(c_i)\,\tilde{p}_i(c_1,c_2;\lambda^H)\right\} = \mathrm{E}_{G^H\times G^L}\left\{J^H(c_1)\,p_1^H(c_1,c_2) + J^L(c_2)\,p_2^H(c_1,c_2)\right\}, \tag{A9}$$

i.e., $\lambda^H$ is the value of $\lambda$ for which the government's expected cost from the minimum cost mechanism that induces firm 1 to adopt technology $L$ is the same as that from the minimum cost no-adoption mechanism. Let $\tilde{K}^H$ be given from (A7) when $\lambda = \lambda^H$, i.e.:

$$\tilde{K}^H = \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^H(c_1)\right) \left(1 - G^L(\tilde{z}^{-1}(c_1;\lambda^H)\right) dc_1\,. \tag{A10}$$

From (A8), $\tilde{K}^L > 0$. Moreover, from (A8) and (A10):

$$\tilde{K}^H - \tilde{K}^L = \int_{\underline{c}}^{\bar{c}} \left(G^L(c_1) - G^L(\tilde{z}^{-1}(c_1;\lambda^H))\right) \left(G^L(c_1) - G^H(c_1)\right) dc_1 > 0\,,$$

[19]The left hand side in (A9) is increasing in $\lambda^H$. Hence, $\lambda^H$ is unique.

because $\tilde{z}^{-1}(c_1;\lambda^H) < c_1$.

To conclude the proof, I need to show that $\tilde{K}^H$ is not lower than the largest adoption cost that firm 1 is willing to pay when facing the minimum cost no-adoption mechanism, i.e.,

$$\tilde{K}^H \geq \int_{\underline{c}}^{\bar{c}} \left(1 - G^L(z^H(c_1))\right) \left(G^L(c_1) - G^H(c_1)\right) dc_1 \,. \tag{A11}$$

Suppose it is not. Consider the following family of mechanisms: firms report their costs; with probability $1-\alpha$ the government selects firm 1 if $c_1 \leq c_2$ and with probability $\alpha$ the government selects firm 1 if $c_1 \leq z^H(c_2)$. As $\alpha$ changes continuously from 0 to 1, firm 1's (gross) benefit from adoption changes continuously from $\tilde{K}^L$ to $\int_{\underline{c}}^{\bar{c}}(1-G^L(z^H(c_1)))(G^L(c_1)-G^H(c_1))dc_1$, and the expected procurement cost continuously increases up to $\mathrm{E}_{G^H\times G^L}\left\{J^H(c_1)p_1^H(c_1,c_2) + J^L(c_2)p_2^H(c_1,c_2)\right\}$. Then, there would be $K > \tilde{K}^H$ for which the government would want to induce firm 1's adoption, which contradicts the definition of $\tilde{K}^H$. Thus, (A11) holds.

## A5 Proof of Proposition 5

The adoption of technology $L$ improves social welfare under complete information if $K \leq \tilde{K}^*$, with $\tilde{K}^*$ given by:

$$\tilde{K}^* = \mathrm{E}_{G^H\times G^L}\left\{\min\{c_1,c_2\}\right\} - \mathrm{E}_{G^L\times G^L}\left\{\min\{c_1,c_2\}\right\} \,. \tag{A12}$$

This equation can be simplified to:

$$\begin{aligned}\tilde{K}^* &= \mathrm{E}_{G^H\times G^L}\left\{c_2 + \min\{c_1 - c_2, 0\}\right\} - \mathrm{E}_{G^L\times G^L}\left\{c_2 + \min\{c_1 - c_2, 0\}\right\} \\ &= \mathrm{E}_{G^L\times G^L}\left\{\max\{c_2 - c_1, 0\}\right\} - \mathrm{E}_{G^H\times G^L}\left\{\max\{c_2 - c_1, 0\}\right\} \\ &= \int_{\underline{c}}^{\bar{c}} G^L(c_1)\left(1 - G^L(c_1)\right) dc_1 - \int_{\underline{c}}^{\bar{c}} G^H(c_1)\left(1 - G^L(c_1)\right) dc_1 \\ &= \tilde{K}^L \,,\end{aligned}$$

where the last equality comes from the definition of $\tilde{K}^L$, while the others follow from algebraic manipulations.

## A6 Proof of Proposition 6

Firm 1 should be selected if and only if $\hat{J}(c_1;\hat{\theta}) \leq J^L(c_2)$, which is equivalent to $c_1 \leq \hat{z}(c_2;\hat{\theta})$.

## A7 Proof of Lemma 1

There will be favoritism of firm 1 if and only if

$$\frac{(1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)}{(1-\hat{\theta})g^L(c)+\hat{\theta}g^H(c)} < \frac{G^L(c)}{g^L(c)}\,.$$

But, this is equivalent to:

$$\frac{(1-\hat{\theta})g^L(c)+\hat{\theta}g^H(c)}{(1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)} > \frac{g^L(c)}{G^L(c)}$$

$$\frac{d}{dc}\ln((1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)) > \frac{d}{dc}\ln G^L(c)$$

$$\frac{d}{dc}\ln\frac{(1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)}{G^L(c)} > 0$$

$$\frac{d}{dc}\frac{(1-\hat{\theta})G^L(c)+\hat{\theta}G^H(c)}{G^L(c)} > 0$$

$$\frac{d}{dc}\frac{G^H(c)}{G^L(c)} > 0\,,$$

which proves the lemma.

## A8 Proof of Lemma 2

The government's best reply to $\hat{\theta}_1$ favors firm 1 more than its best reply to $\hat{\theta}_0$ if and only if:

$$\frac{(1-\hat{\theta}_1)G^L(c)+\hat{\theta}_1G^H(c)}{(1-\hat{\theta}_1)g^L(c)+\hat{\theta}_1g^H(c)} < \frac{(1-\hat{\theta}_0)G^L(c)+\hat{\theta}_0G^H(c)}{(1-\hat{\theta}_0)g^L(c)+\hat{\theta}_0g^H(c)}\,,$$

which is equivalent to:

$$\frac{d}{dc}\left(\frac{(1-\hat{\theta}_1)+\hat{\theta}_1\dfrac{G^H(c)}{G^L(c)}}{(1-\hat{\theta}_0)+\hat{\theta}_0\dfrac{G^H(c)}{G^L(c)}}\right) > 0\,. \tag{A13}$$

Define the function $\phi(x)$ as:

$$\phi(x) = \frac{(1-\hat{\theta}_1)+\hat{\theta}_1x}{(1-\hat{\theta}_0)+\hat{\theta}_0x}\,.$$

Its derivative is given by:

$$\frac{d\phi(x)}{dx} = \frac{\hat{\theta}_1}{(1-\hat{\theta}_0)+\hat{\theta}_0 x} - \frac{\hat{\theta}_0}{(1-\hat{\theta}_0)+\hat{\theta}_0 x}\phi(x)\,.$$

For $x \in (0,1]$, we will have $\phi(x) \leq 1$, and

$$\frac{d\phi(x)}{dx} \geq \frac{\hat{\theta}_1 - \hat{\theta}_0}{(1-\hat{\theta}_0)+\hat{\theta}_0 x}\,,$$

which is positive if and only if $\hat{\theta}_1 > \hat{\theta}_0$. It is now sufficient to recall that $G^H(c) < G^L(c)$, and $G^H(c)/G^L(c)$ is increasing, to conclude that (A13) is satisfied.

## A9 Proof of Lemma 3

Firm 1's (gross) benefit from the adoption of technology $L$, when facing the government's best reply to $\hat{\theta}$ is $\int_{\underline{c}}^{\bar{c}} \Big(1 - G^L(\hat{z}^{-1}(c_1;\hat{\theta}))\Big)\Big(G^L(c_1) - G^H(c_1)\Big)\, dc_1$. Given that $\hat{z}^{-1}(c;\hat{\theta})$ is decreasing with $\hat{\theta}$, the benefit from the adoption is increasing in $\hat{\theta}$.

## A10 Proof of Proposition 7

Let $\hat{K}^L$ and $\hat{K}^H$ be given as:

$$\hat{K}^L = \hat{\kappa}(0) = \int_{\underline{c}}^{\bar{c}} \Big(1 - G^L(c_1)\Big)\Big(G^L(c_1) - G^H(c_1)\Big)\, dc_1 \tag{A14}$$

$$\begin{aligned}\hat{K}^H &= \hat{\kappa}(1) = \int_{\underline{c}}^{\bar{c}} \Big(1 - G^L(\hat{z}^{-1}(c_1;1)\Big)\Big(G^L(c_1) - G^H(c_1)\Big)\, dc_1 \\ &= \int_{\underline{c}}^{\bar{c}} \Big(1 - G^L(z^{H^{-1}}(c_1;1)\Big)\Big(G^L(c_1) - G^H(c_1)\Big)\, dc_1\,.\end{aligned} \tag{A15}$$

We have $\hat{K}^L > 0$ and, from Lemma 3, $\hat{K}^L < \hat{K}^H$. By construction of $\hat{K}^L$ and $\hat{K}^H$, and the analysis in the text, one may conclude that the proposition describes a government's best reply to firm 1, and firm 1's best reply to the government. Therefore, it describes the agents' equilibrium behavior.

# Appendix B  A Numerical Example

In this appendix I develop a numeric example of the model. The technologies are described by the densities $g^L(c) = 1$ and $g^H(c) = 2(c-1)$, with $c \in [1,2]$. The virtual cost functions are $J^L(c) = 2c - 1$ and $J^H(c) = \frac{3c-1}{2}$.

## B1  The optimal mechanism under full commitment

### B1.1  Low adoption cost ($K \leq \tilde{K}^L$)

If $K \leq \tilde{K}^L$, the government selects the firm that reports the lowest cost, i.e., $p_1^L(c_1, c_2) = 1$ if and only if $c_1 \leq c_2$. Figure B1 represents this selection rule in the space of costs.

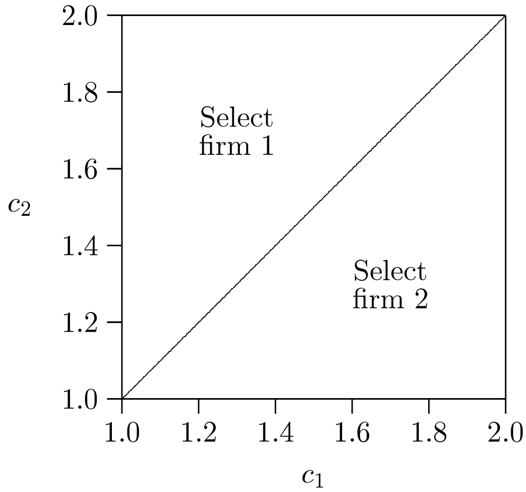


Figure B1: Selection if firm 1 adopts.

One gets the following functions:

$$P_1^L(c_1) = \mathrm{E}_{G^L}\left\{p_1^L(c_1, c_2)\right\} = 2 - c_1\,,$$

$$\pi_1^L(c_1) = \int_{c_1}^{2} P_1^L(x)dx = \frac{1}{2}\left(2 - c_1^2\right)^2\,,$$

$$\mathrm{E}_{G^L}\left\{\pi_1^L(c_1)\right\} = \frac{1}{6}\,.$$

Therefore, the cost of adoption must be no greater than:

$$\tilde{K}^L = \mathrm{E}_{G^L}\left\{\pi_1^L(c_1)\right\} - \mathrm{E}_{G^H}\left\{\pi_1^L(c_1)\right\} = \frac{1}{12}\,, \tag{B1}$$

and the government's expected procurement cost is:

$$C_G^L = \mathrm{E}_{G^L \times G^L} \left\{ J^L(c_1)\, p_1^L(c_1, c_2) + J^L(c_2)\, p_2^L(c_1, c_2) \right\} = \frac{5}{3}\,. \tag{B2}$$

### B1.2 High adoption cost ($\boldsymbol{K > \tilde{K}^{\mathrm{H}}}$)

If the adoption cost is sufficiently high, firm 1 does not adopt technology $L$ and $p_1^H(c_1, c_2) = 1$ if and only if $3c_1 \leq 4c_2 - 1$. Figure B2 represents this selection rule in the space of costs.

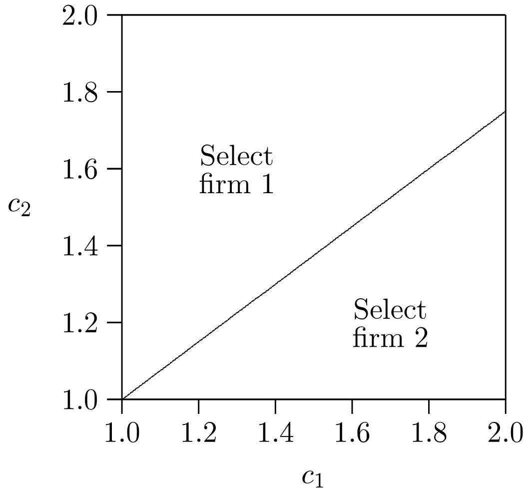


Figure B2: Selection if firm 1 does not adopt.

One gets the following functions:

$$\begin{aligned}
P_1^H(c_1) &= \mathrm{E}_{G^L} \left\{ p_1^H(c_1, c_2) \right\} = \frac{7 - 3c_1}{4}\,, \\
\pi_1^H(c_1) &= \int_{c_1}^{2} P_1^H(x) dx = \frac{(8 - 3c_1)(2 - c_1)}{8}\,, \\
\mathrm{E}_{G^H} \left\{ \pi_1^H(c_1) \right\} &= \frac{7}{48}\,.
\end{aligned}$$

The cost of adoption must be sufficiently high:

$$\tilde{K}^H > \mathrm{E}_{G^L} \left\{ \pi_1^H(c_1) \right\} - \mathrm{E}_{G^H} \left\{ \pi_1^H(c_1) \right\} = \frac{5}{48}\,, \tag{B3}$$

and the government's expected procurement cost is:

$$C_G^H = \mathrm{E}_{G^H \times G^L} \left\{ J^H(c_1) p_1^H(c_1, c_2) + J^L(c_2) p_2^H(c_1, c_2) \right\} = \frac{55}{32} \,. \tag{B4}$$

The government favors firm 1. This can be seen from Figure B2 where the boundary between the regions for selection of either firm is below the diagonal.

### B1.3 Intermediate adoption cost ($\tilde{K}^{\mathrm{L}} < K \leq \tilde{K}^{\mathrm{H}}$)

For intermediate values of the adoption cost, firm 1 will adopt technology $L$ but the government will favor it. The adjusted virtual cost of firm 1 is:

$$\tilde{J}(c; \lambda) = 2c - 1 - (2 - c)(c - 1)\lambda \,, \tag{B5}$$

which is increasing for all $c$ if and only if $\lambda \leq 2$. Otherwise, it decreases for $c \in [1, (3\lambda - 2)/(2\lambda))$, and it increases for $c \in ((3\lambda - 2)/(2\lambda), 2]$. The function $\tilde{J}(\cdot; \lambda)$ is depicted in Figure B3, for several values of $\lambda$.

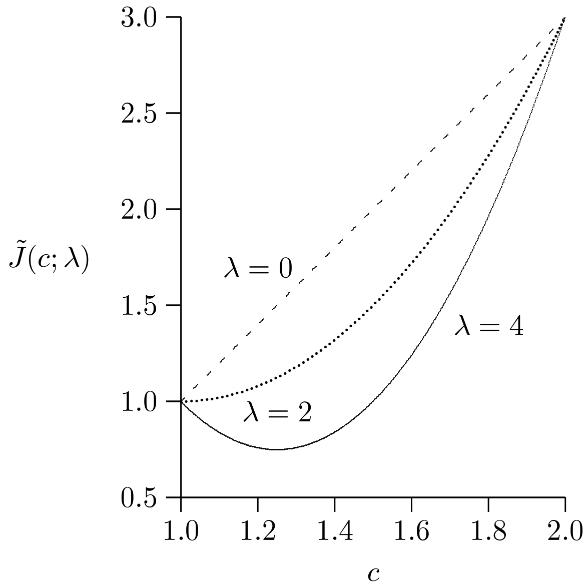


Figure B3: The function $\tilde{J}(\cdot; \lambda)$.

Consider first that $\lambda \leq 2$ (the regular case). Then $\tilde{p}_1(c_1, c_2; \lambda) = 1$ if and only if $c_2 \geq c_1 - \frac{1}{2}(2 - c_1)(c_1 - 1)\lambda$. Figure B4 represents this selection rule in the space of costs, for a value of $\lambda = 1$.

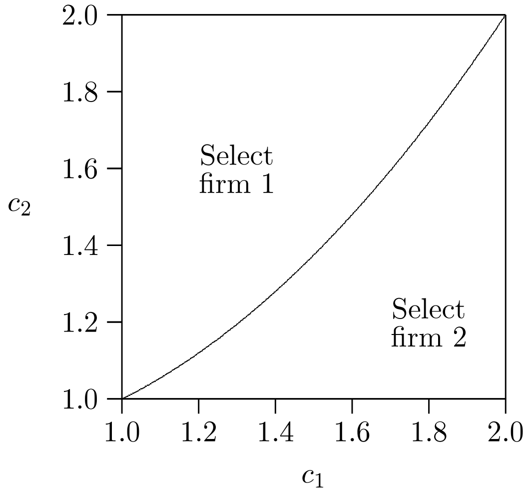


Figure B4: Selection if firm 1 is induced to adopt and $\lambda = 1$.

One gets the following functions:

$$\tilde{P}_1(c_1;\lambda) = \mathrm{E}_{G^L}\left\{\tilde{p}_1(c_1,c_2;\lambda)\right\} = \frac{1}{2}\left(2-c_1\right)\left(2+(c_1-1)\lambda\right) ,$$
$$\tilde{\pi}_1(c_1;\lambda) = \int_{c_1}^{2}\tilde{P}_1(x;\lambda)dx = \frac{1}{12}\left(2-c_1\right)^2\left(6+(2c_1-1)\,\lambda\right) ,$$
$$\mathrm{E}_{G^L}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} = \frac{4+\lambda}{24} ,$$
$$\tilde{\kappa}(\lambda) = \mathrm{E}_{G^L}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} - \mathrm{E}_{G^H}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} = \frac{5+\lambda}{60} .$$

The government's expected procurement cost is:

$$\tilde{C}_G(\lambda) = \mathrm{E}_{G^L\times G^L}\left\{J^L(c_1)\tilde{p}_1(c_1,c_2;\lambda) + J^L(c_2)\tilde{p}_2(c_1,c_2;\lambda)\right\} = \frac{200+\lambda^2}{120} . \tag{B6}$$

But $C_G(2) = 17/10 < 55/32$. Therefore, by continuity, if $\lambda$ is slightly greater than 2, the government will still want to induce firm 1 to adopt. Consider now the case of $\lambda > 2$ (the non-regular case). The function $\tilde{J}(\cdot;\lambda)$ is decreasing in a neighborhood of 1. It will be below 1, the lowest possible value for $J^L(c)$, while $c_1 \leq 2(\lambda-1)/\lambda$. Thus, $\tilde{p}_1(c_1,c_2;\lambda) = 1$ if and only if $c_2 \geq \max\{1, c_1 - \frac{1}{2}(2-c_1)(c_1-1)\lambda\}$. Figure B5 represents this selection rule in the space of costs, for a value of $\lambda = 2.5$.

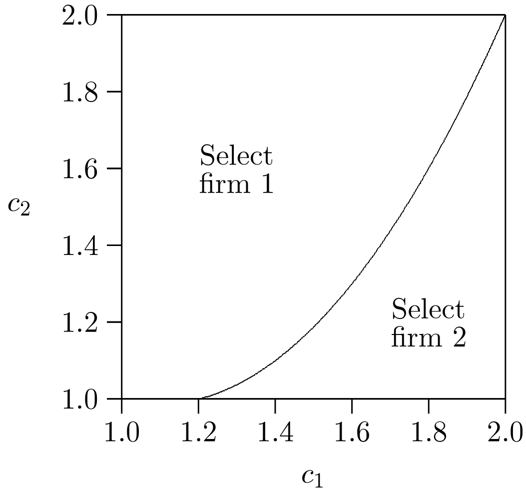


Figure B5: Selection if firm 1 is induced to adopt and $\lambda = 2.5$.

One gets the following functions:

$$\tilde{P}_1(c_1;\lambda) = \mathrm{E}_{G^L}\left\{\tilde{p}_1(c_1,c_2;\lambda)\right\} = \begin{cases} 1 & \text{if } c_1 \leq \dfrac{2(\lambda-1)}{\lambda} \\ \dfrac{1}{2}\left(2-c_1\right)\left(2+(c_1-1)\lambda\right) & \text{if } c_1 > \dfrac{2(\lambda-1)}{\lambda} \end{cases},$$

$$\tilde{\pi}_1(c_1;\lambda) = \int_{c_1}^{2} \tilde{P}_1(x;\lambda)dx = \begin{cases} \dfrac{6\lambda^2-3\lambda+2}{3\lambda^2} - c_1 & \text{if } c_1 \leq \dfrac{2(\lambda-1)}{\lambda} \\ \dfrac{1}{12}(2-c_1)^2\left(6+(2c_1-1)\lambda\right) & \text{if } c_1 > \dfrac{2(\lambda-1)}{\lambda} \end{cases},$$

$$\mathrm{E}_{G^L}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} = \frac{3\lambda^3-6\lambda^2+8\lambda-4}{6\lambda^3},$$

$$\tilde{\kappa}(\lambda) = \mathrm{E}_{G^L}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} - \mathrm{E}_{G^H}\left\{\tilde{\pi}_1(c_1;\lambda)\right\} = \frac{5\lambda^4-20\lambda^2+40\lambda-24}{30\lambda^4}. \quad \text{(B7)}$$

The government's expected procurement cost is:

$$\tilde{C}_G(\lambda) = \mathrm{E}_{G^L\times G^L}\left\{J^L(c_1)\tilde{p}_1(c_1,c_2;\lambda) + J^L(c_2)\tilde{p}_2(c_1,c_2;\lambda)\right\} = \frac{2\left(15\lambda^3-10\lambda^2+15\lambda-8\right)}{15\lambda^3}. \quad \text{(B8)}$$

From a numerical approximation, one obtains that this expression is equal to 55/32 when $\lambda = \lambda^H =$

2.50891. So, from (B7):[20]

$$\tilde{K}^H = \tilde{\kappa}(2.50891) = \frac{1}{8}\,. \tag{B9}$$

Figures B6 and B7 plot the relationships between $\lambda$ and $K$, and $C_G$ and $K$, in its intermediate range.

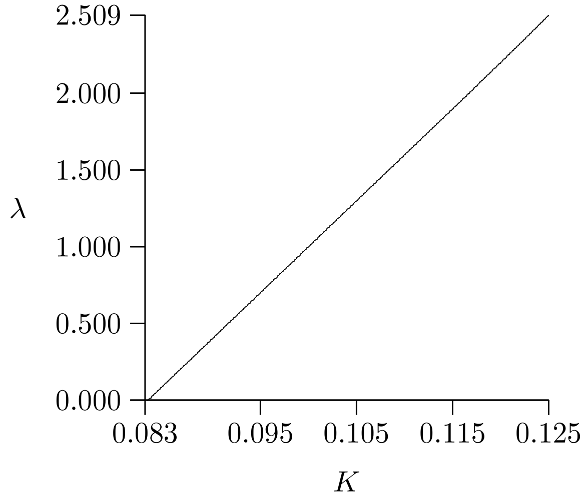


Figure B6: Relation between $K$ and $\lambda$.

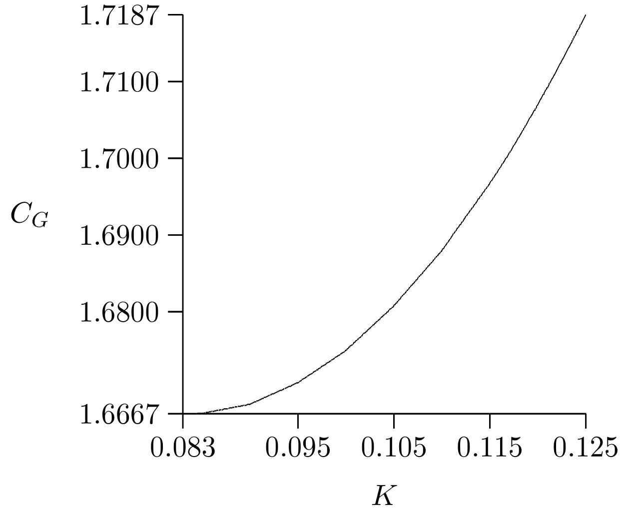


Figure B7: Relation between $K$ and the Expected Procurement Cost.

[20] Note that this value of $\tilde{K}^H$ satisfies condition (B3).

### B1.4 Summary

The optimal mechanism is such that:

- If $K \leq 1/12$: firm 1 adopts and the government selects it if and only if $c_1 \leq c_2$;
- If $1/12 < K \leq 7/60$ firm adopts and the government selects it if and only if $c_2 \geq c_1 - \frac{1}{2}(2 - c_1)(c_1 - 1)\lambda$
- If $7/60 < K \leq 1/8$, firm 1 adopts and the government selects it if and only if $c_2 \geq \max\{1, c_1 - \frac{1}{2}(2 - c_1)(c_1 - 1)\lambda\}$;
- If $K > 1/8$, firm 1 keeps technology $H$, and the government and the government selects it if and only if $3c_1 \leq 4c_2 - 1$.

Figure B8 summarizes this description.

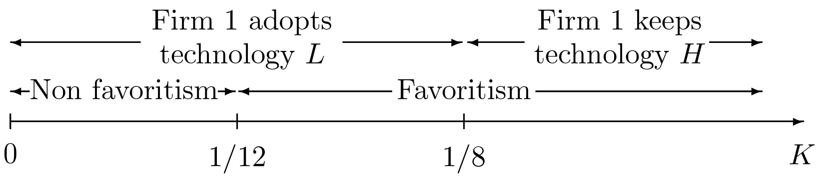


Figure B8: Equilibrium behavior in the full commitment case.

## B2 The case of limited commitment

The optimal mechanism under government's limited commitment differs from the one under its full commitment only for intermediate values of the adoption cost. If $K \leq \hat{K}^L = 1/12$, firm 1 will adopt technology $L$ for sure. If $K > \hat{K}^H = 5/48$, firm 1 will not adopt for sure. In either case the government will respond optimally and there is no difference between the full and the limited commitment cases.

### B2.1 Intermediate adoption cost ($\hat{K}^{\mathrm{L}} < K \leq \hat{K}^{\mathrm{H}}$)

For intermediate values of the adoption cost, firm 1 will keep technology $H$ with probability $\theta$, and the government will respond optimally to this adoption strategy. The adjusted virtual cost for firm 1 is given by:

$$\hat{J}(c;\theta) = c_1 + \frac{(c-1)(1-(2-c)\theta)}{1+(2c-3)\theta}.$$

This function is increasing in $c$ and decreasing in $\theta$. It is presented in Figure B9 for several values of $\theta$.

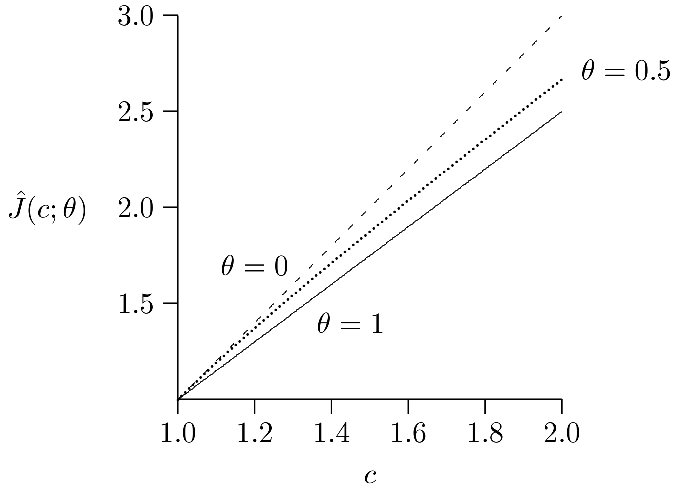


Figure B9: The function $\hat{J}(\cdot;\theta)$.

It follows that $\hat{p}_1(c_1,c_2;\theta) = 1$ if and only if $c_2 \geq \frac{1}{2}(1 + c_1 + \frac{(c_1-1)(1-(2-c)\theta)}{1+(2c-3)\theta})$. Figure B10 represents this selection rule in the space of costs, for a value of $\theta = 1/2$.

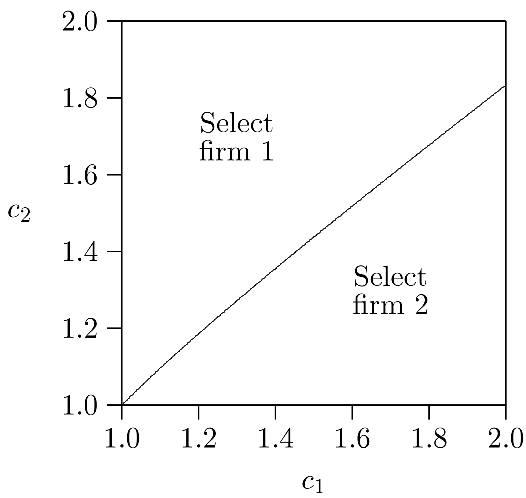


Figure B10: Selection if firm 1 is induced to adopt and $\theta = 0.5$.

One gets the following functions:

$$\hat{P}_1(c_1;\theta) = \mathrm{E}_{G^L}\left\{\hat{p}_1(c_1,c_2;\theta)\right\} = \frac{2(2-c_1) - (3c_1^2 - 12c_1 + 11)\theta}{2(1+(2c_1-3)\theta)},$$

$$\hat{\pi}_1(c_1;\theta) = \int_{c_1}^{2} \hat{P}_1(x;\theta)dx = \frac{(1-\theta)^2 \ln\left(\frac{1+\theta}{2\theta c_1 - 3\theta + 1}\right)}{16\theta^2} + \frac{3\theta c_1^2 + (1-15\theta)c_1 + 2(9\theta - 1)}{8\theta},$$

$$\mathrm{E}_{G^L}\left\{\hat{\pi}_1(c_1;\theta)\right\} = \frac{(1-\theta)^3 \ln\left(\frac{1-\theta}{1+\theta}\right) + 2\theta\left(6\theta^2 - 3\theta + 1\right)}{32\theta^3},$$

$$\mathrm{E}_{G^H}\left\{\hat{\pi}_1(c_1;\theta)\right\} = \frac{3(1-\theta)^4 \ln\left(\frac{1+\theta}{1-\theta}\right) + 2\theta\left(24\theta^3 - 19\theta^2 + 12\theta - 3\right)}{192\theta^4},$$

$$\hat{\kappa}(\theta) = \frac{3(1-\theta)^3(1+\theta) \ln\left(\frac{1-\theta}{1+\theta}\right) + 2\theta\left(12\theta^3 + \theta^2 - 6\theta + 3\right)}{192\theta^4}.$$

The government's cost will then be:

$$\begin{aligned}\hat{C}_G(\theta) &= \mathrm{E}_{((1-\theta)G^L+\theta G^H)\times G^L}\left\{\hat{J}^L(c_1;\theta)\hat{p}_1(c_1,c_2;\theta) + J^L(c_2)\hat{p}_2(c_1,c_2;\theta)\right\} \\ &= \frac{(1-\theta)^4 \ln\left(\frac{1-\theta}{1+\theta}\right) + 2\theta\left(113\theta^2 - 4\theta + 1\right)}{128\theta^3}. \qquad \text{(B10)}\end{aligned}$$

Figures B11 and B12 plot the relationships between $\theta$ and $K$, and $C_G$ and $K$, in its intermediate range.

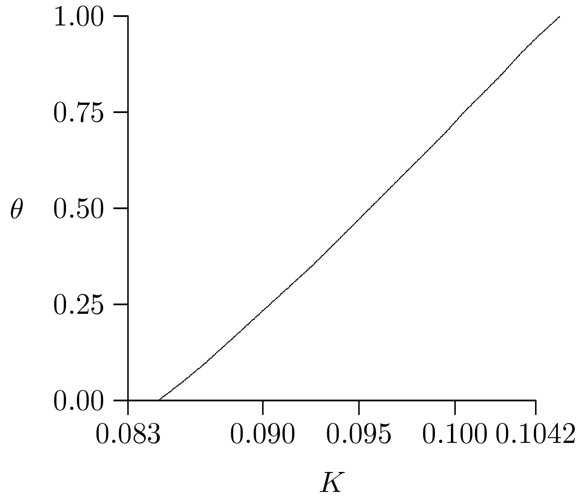


Figure B11: Relation between $K$ and $\theta$.

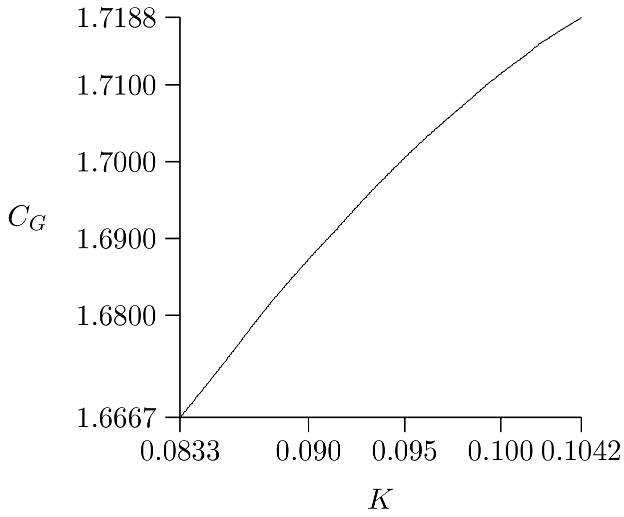


Figure B12: Relation between $K$ and Expected Procurement Cost.

### B2.2 Summary

The optimal mechanism is such that:

- If $K \leq 1/12$: firm 1 adopts and the government selects it if and only if $c_1 \leq c_2$;
- If $1/12 < K \leq 5/48$ firm adopts and the government selects it if and only if $c_2 \geq \frac{1}{2}(1 + c_1 + \frac{(c_1-1)(1-(2-c)\theta)}{1+(2c-3)\theta})$;
- If $K > 5/48$, firm 1 keeps technology $H$, and the government selects it if and only if $3c_1 \leq 4c_2 - 1$.

Figure B13 summarizes this description.

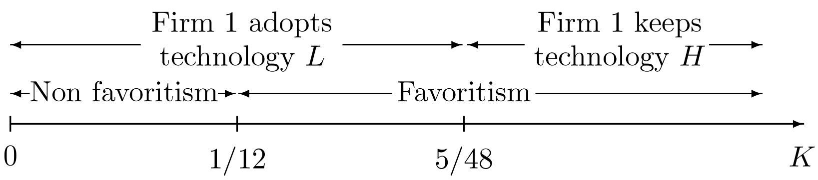


Figure B13: Equilibrium behavior in the limited commitment case.

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