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LARGE SHAREHOLDERS, PRIVATE BENEFITS OF CONTROL, AND OPTIMAL SCHEMES OF PRIVATIZATION

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Abstract

We analyze optimal schemes for privatization of state enterprises when foreign investors are potential buyers. The highest bidders may not be the best large shareholders for the state enterprise, since their bid may only reflect their high private benefit of control. The government finds itself facing a trade-off between trying to obtain the highest possible payment (the "revenue" objective) and identifying the company which will operate better in the future (the "efficiency" objective). Therefore, ordinary auctions are not appropriate. Our optimal privatization schemes in many cases require the use of the number of shares sold as a crucial instrument to attract the most efficient investors.

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1. Introduction

Privatization of state enterprises has been a major task of many governments all over the world. Various issues arise during the process and not all of them have been addressed in the economics literature. One of these problems arises when the potential buyers are foreign companies. This problem is particularly acute in Eastern Europe, where governments are actively encouraging foreign investors to buy shares of former state enterprises. The argument is that foreign investors, as large controlling shareholders, may bring advanced technology, modern managerial skills, better product quality, and access to both product and financial markets in the West.[1] In other words, giving control to a foreign company may considerably improve the value of the privatized firm. Meanwhile, domestic citizens who hold minority stakes in the same firm can free-ride on such improvements.

However, foreign control of the domestic firm may also impose costs on domestic shareholders, since the foreign majority shareholder may have objectives other than maximizing the firm's value. In particular, he may try to obtain large private benefits of control, which cannot be shared by domestic shareholders. Private benefits of control stem from the imperfect market environment in transitional economies. In these economies, the control right usually gives the foreign company enormous market power. For example, recently Fiat, Mercedes-Benz, and Volkswagen acquired majority stakes in several Eastern European car makers. These companies may not necessarily believe that the acquired factories *per se* have great potential value. However, these acquisitions have significant strategic value in allowing early entries to the East European automobile market. This is only to their private benefit. In the extreme case, a foreign firm may first buy a potential future competitor just to close it down.[2] This concern has been voiced in the process of privatization and has often been used to justify the sale of control only to domestic shareholders rather than to foreign companies.[3] One may argue that asking the buyer to commit to a certain level of investment might solve the problem. However, as the experience of Volkswagen with Skoda has shown, such a solution is very often subject to renegotiation. Once the buyer has taken control over the domestic firm, it is very easy to claim that, because of a change of circumstances or a lack of funds, it is not able to undertake such investments.

The purpose of this paper is to highlight these economic dilemmas and to show how the government can screen among potential buyers with different plans. The premise is that the government does not know the intentions of potential corporate buyers. As an objective, the government strikes

[1] See, for example, Aghion and Burgess (1991).

[2] Such concern was expressed when Anheuser-Busch, selling Budweiser worldwide except Europe, was attempting to buy shares of the Czech state brewer Budvar, maker of the European brand of Budweiser beer (Central European Business Weekly, 1994).

[3] For example, in the case of the sale of Ikarus, a Hungarian bus manufacturer, Hungarian authorities argued that a European strategic investor would have been interested in running down Ikarus in order to eliminate a competitor. The Hungarian authorities thus preferred a domestic buyer, even if the offer was lower (Financial Times, 2-7-91).

a balance between obtaining a high payment today ("the revenue" objective) and increasing the value of the firm in the future (the "efficiency" objective). Due to the potential private benefits accruing to controlling shareholders, these two objectives are not mutually consistent. As a result, ordinary auctions do not achieve economic efficiency, since the highest bidder may not be the large shareholder which maximizes the value of the firm.

The government must choose the appropriate buyer and how large a controlling interest will be sold. We show that the number of shares sold to the controlling shareholder is a crucial instrument for the government to use in achieving its objectives.

We identify a very simple scheme where, rather than commit to the sale of a given number of shares of the firm, the government grants a greater number of controlling share the higher the winning bid. This last feature will guarantee that the highest bidder will be the most efficient investor. The intuition is that an efficient investor would like to obtain as many shares as possible, since the shares will have a high value, while an investor interested mainly in the private benefit of control attaches less value to the shares in excess of the minimum required to control the firm.

The paper follows the literature on optimal auctions. Since the seller's objective is a combination of efficiency and revenue and bidders differ in both these dimensions, these two objectives potentially conflict across bidders. Thus, using just two instruments (the probability of winning and the price paid) is insufficient to identify the most desirable buyer. A third instrument (the number of shares to be sold) must be introduced. Our paper departs from most of this literature in one key aspect. Unlike other cases in which quantity is also considered (e.g. Maskin and Riley, 1990) or some instrument is introduced to take into account of the firm's performance after the auction (for example, the cost level in Laffont and Tirole, 1993), the third instrument is costly for the government and this cost is higher the higher is the value of the firm. Therefore, the government faces a trade-off between screening more effectively among bidders by using this third instrument and selling fewer shares.

Before introducing the formal model, we discuss in Section 2 the objectives of the government and of the foreign investors and we present in Section 3 a simple numerical example to convey the main intuition of the paper. Sections 4 and 5 describe the model and derive the optimal privatization scheme. Section 6 analyzes the robustness of the results when some of the assumptions are relaxed. Finally, Section 7 concludes.

2. Objectives of Government and Investors

2.1. The Government's Objective: Revenue vs. Efficiency

We consider a government which plans to privatize a large state enterprise.[4] Two leading goals of privatization stand out among others. The first is to maximize total revenues from the process of privatization. The second is to maximize the value of the privatized firm under the control of the new owner. From an economic point of view, Maskin (1992) argues convincingly that the government should maximize the value of the firm (efficiency objective). Kornai (1991) expresses the same view and justifies it on the ground of social philosophy. Judging from limited observations of the practice of various countries, it seems that this efficiency objective has been adopted by most governments. Indeed, the sale of control to foreign companies is encouraged on the ground that it may increase the value of the domestic firm. Against these potential gains, the government must weigh the loss of future dividends, as well as other political and economic costs of foreign control. Other things being equal, a government will typically prefer to minimize the number of shares sold to foreign investors.

Governments will also strive to maximize revenues earned through privatization, especially those facing post-socialist transition, as these revenues will help to ease the long and costly process of economic restructuring. Bolton and Roland (1992) point out that major budgetary problems may arise as a larger share of the economy becomes private, since a greater fraction of the firm's profit is no longer remitted to the state. A second reason for governments to embrace a revenue maximization goal arises from the privatization process *per se*. As was explained by Boycko, Shleifer and Vishny (1993), there are many incumbent claimants to the control right of the firm and therefore the central government needs to bribe these claimants. A third reason for maximizing revenues is also political. Public opinion is generally opposed to selling assets abroad, since it is feared that foreign companies may take advantage of the situation to appropriate the already scarce capital of the country. A large amount of revenue may therefore be necessary in order to justify domestically the decision to give part of the ownership to foreign firms (Cornelli, 1993).

To take into account both of these objectives, we assume that the government maximizes a weighted sum of revenue and efficiency. Since the latter objective has been most apparent, and is the most compelling for governments in Eastern Europe and the former Soviet Union, we assume the government gives a heavier weight to the firm's value than to revenue maximization.

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[4] Since the value of the shares of the firm must be equal to the value of the whole firm minus the value of the debt, to the extent that the firm's debt is secured and riskless, we will not lose generality by assuming in the rest of the chapter that the firm is an all-equity firm.

2.2. The Investors' Objective: Private Benefit vs. Public Value

As discussed in the introduction, the control right to a firm entitles the controlling shareholder to two kinds of benefits: public benefits, which are in proportion to the share of the company he owns and private benefits of control, which cannot be shared by other (minority) shareholders.

Consider, then, the case where control of the domestic firm may be given to one of n alternative foreign corporations. The public value of the firm is its expected present value, and will depend crucially upon which of the foreign corporations is granted control. Let v_i be the public value of the firm when under control of foreign corporation i. Each of the foreign corporations also realizes a private benefit, B_i, upon gaining control of the firm. Both v_i and B_i are private information to buyer i and can be seen as estimated future uncertain flows of public and private benefits, discounted at the appropriate rate of return (taking risk factors into account). The controlling shareholder must obtain at least $\underline{\alpha}$ shares. If α is the number of shares that the controlling shareholder obtains, then these α shares will be worth $\alpha v + B$ to him. The public value v is shared by the large and the small shareholders, while the private benefit B is solely enjoyed by the controlling large shareholder.

For the convenience of illustration, let us assume for a moment that there are only two potential buyers: buyer 1 with (v_1, B_1) and buyer 2 with (v_2, B_2). If $v_1 \geq v_2$ and $B_1 \geq B_2$, there is no trade-off between the two objectives of the government: the buyer that maximizes the firm's value is also the buyer that is willing to pay the most for the controlling share. This is regardless of α. Then the analysis is equivalent to the one in standard auctions, where the seller maximizes revenues and the optimal mechanism for the government is an auction to sell $\underline{\alpha}$ shares to the highest bidder, which is also the most efficient buyer.

However, assume that $v_1 \geq v_2$, but $B_1 \leq B_2$. Then it may be that for some α_1, $\alpha_1 v_1 + B_1 < \alpha_1 v_2 + B_2$. In this case, there is a trade-off between the two objectives of the government. Depending on α, the highest bidder may not be the most efficient buyer. For the rest of the paper, we will focus on the case in which v_i and B_i are negatively related.

The parameters v_i and B_i can also be reinterpreted as characteristics of the foreign investors' restructuring plans after obtaining the control of the domestic firm. In general, we expect that v_i and B_i are negatively related. The more a foreign company invests and increases the value of the firm, the less it will exploit the firm by abusing the control right. This is particularly true if the private benefit of control is obtained by buying the output of the domestic firm at a below-market price, or by diverting profits from the domestic firm into the controlling firm. More generally, we can regard the combinations of v_i, B_i on an "efficiency frontier." Foreign investors will always try to increase the profits of the controlled firm up to a point in which another increase in private benefits can come only at the expense of the value of the domestic firm.

2.3. The payoffs

Now that we have characterized both the government's and the investors' interests, we can express their payoff functions. Let us define p_i as the probability that company i obtains the control and t_i the payment it has to make to the government. We assume that a foreign company is risk neutral and therefore its expected payoff is

$$E[(\alpha v_i + B_i)p_i - t_i],$$

where v_i and B_i are private information of the company.

The government is also risk-neutral and maximizes a weighted sum of revenues and efficiency. As a measure of efficiency, we use the total value of shares owned by domestic shareholders. The government's expected payoff becomes:

$$E[\lambda \sum_i t_i + (1-\lambda) \sum_i (1-\alpha) v_i p_i],$$

where $0 \leq \lambda \leq \frac{1}{2}$ is the governments weight on the revenue objective, since in general we assume that the government cares more about value (efficiency).[5]

We use $(1-\alpha)v_i$ to model the efficiency component in the objective function. On the one hand, the government wants to maximize the value of the firm, v_i, because it maximizes the value of the shares remaining in domestic hands and because it generates positive externalities in the whole economy, such as higher employment, more social stability, and more businesses for up-stream and down stream firms. At the same time, when the number of shares in the hands of a foreign company increases, future dividends accruing to domestic shareholders will be lower. In other words, the government would like to give the control to the most efficient foreign company, but finds costly to give such company more shares than the minimum necessary to obtain the control, $\underline{\alpha}$.

The most general way to measure the efficiency component should therefore be $v_i - C(\alpha v_i)$, where the second term represents the cost of selling α shares when the value is v_i. Let us assume that $C(\alpha v_i) = \gamma \alpha v_i$ and consider two possibilities. If $\gamma = 0$ the government is interested in the entire value v_i (the government cares only about the externalities) and there is no cost in selling shares. If $\gamma = 1$, instead, the government cares only about the value of the shares remaining in domestic hands (i.e. about future dividends). By setting $\gamma = 1$, therefore, we simplify the objective function but we

[5]We are here implicitly assuming that if the firm remains in domestic hands its value will be 0. As a result, the government will always choose to sell the control to a foreign company. This assumption could easily be relaxed by introducing a minimum threshold necessary in order to induce the government to sell the control abroad. For simplicity, we ignore this issue in the paper.

may be overestimating the cost of selling shares (or, alternatively, underestimating the benefits of attracting an efficient buyer). However, what is crucial from our analysis is that selling more shares is costly and therefore the basic results of our analysis should remain valid also for more general cases where γ is less than 1.[6]

It seems unlikely that the government's privatization process will be limited to the sale of a single firm. Instead, we expect to see a series of domestic enterprises privatized, and hence a series of auctions. However, the domestic firm being sold in each auction will differ and so will the potential buyers.[7] Even if a foreign company revealed—during the auction—the value of the domestic firm under its control, this may contain no information regarding the next firm sold: synergies may differ and plans may change. We therefore assume we can ignore the effects of reputation that would arise in a repeated auction.

3. Numerical Example

In this section we present a numerical example to convey the main intuition behind the mechanism we will analyze. We first assume that the number of shares to be sold, α, is chosen and fixed before the actual sale and show why the government may sometimes want to commit to selling a number of shares higher than the bare minimum required to control the firm. As a second step, we show how the same result can be achieved at a lower cost when the government makes the number of shares sold contingent on the offers.

Let us assume that there are two potential buyers: buyer 1 has $v_1 = 100$ and $B_1 = 40$ and buyer 2 has $v_2 = 130$ and $B_2 = 20$. In other words, buyer 2 is more efficient than buyer 1. On the side of the government, let us assume that $\lambda = \frac{1}{4}$ and that the minimum number of shares necessary to obtain the control right is $\underline{\alpha} = 50\%$. The total willingness to pay of each company, w_i, for different values of α, is given in the table.

Suppose the government sells the α shares through an English auction. Then, if the government decides to sell 50% of the firm, company 1 will win the auction with a bid of 85. The payoff to the government is $R = \lambda 85 + (1-\lambda)(1-\alpha)100 = 58.75$. If the government sells $\alpha = \frac{2}{3}$ shares (actually slightly more than $\frac{2}{3}$), the winner is now company 2 for a price of 106.67. The payoff to the government is $R = 59.17$. If the government auctions 70% of the shares, company 2 wins the auction with a price of 110. The payoff is $R = 56.75$.

[6] Notice that we are assuming that $\lambda \leq \frac{1}{2}$. Therefore, even if we set $\gamma = 1$, somehow minimizing the importance of v_i, we may compensate such assumption by reducing λ. Actually, the fact itself that v_i has importance not only because of the future revenues, could be a justification of the assumption $\lambda < \frac{1}{2}$.

[7] This is particularly true in Eastern Europe, where, because of economic planning, often there is only one firm per industry.

w_i \ α	Company 1 $v_1 = 100, B_1 = 40$	Company 2 $v_2 = 130, B_2 = 20$
$\alpha = 50\%$	$w_1 = \alpha v_1 + B_1 = 90$	$w_2 = \alpha v_2 + B_2 = 85$
$\alpha = \frac{2}{3}$	$w_1 = \alpha v_1 + B_1 = 106.67$	$w_2 = \alpha v_2 + B_2 = 106.67$
$\alpha = 70\%$	$w_1 = \alpha v_1 + B_1 = 110$	$w_2 = \alpha v_2 + B_2 = 111$

It is clear why the value of α influences who wins the auction: when α increases, the willingness to pay of company 2 increases more rapidly than that of company 1. When α is low, the auction attributes the control to an inefficient company (company 1). By increasing the number of shares the government changes the final result of the auction and reaches the right balance among the two objectives.

If the government commits to selling a fixed number of shares, the optimal number of shares is $\alpha = \frac{2}{3}$. In fact, if the government increases the number of shares sold to $\frac{2}{3} + \Delta\alpha$, the revenues increase by $\frac{1}{4}v_1\Delta\alpha = \frac{1}{4} \times 100\Delta\alpha$ but the government loses in value $\frac{3}{4}v_2\Delta\alpha = \frac{3}{4} \times 130\Delta\alpha$. Secondly, the government would never sell $50\% < \alpha < \frac{2}{3}$. In this range, in fact, the winner is always company 1. By selling $\Delta\alpha$ shares less, the government gains in value $\frac{3}{4}v_1\Delta\alpha = \frac{3}{4} \times 100\Delta\alpha$, but only loses in revenues $\frac{1}{4}v_2\Delta\alpha = \frac{1}{4} \times 130\Delta\alpha$. In summary, the government either chooses $\alpha = 50\%$ or $\alpha = \frac{2}{3}$. The $\alpha = 50\%$ choice makes the low value company, company 1, the winner. The $\alpha = \frac{2}{3}$ makes the high value company, company 2, the winner. In this specific example, $\alpha = \frac{2}{3}$ is better.

Next, we show that the government can do even better if it does not commit to selling a given α in advance, but instead sells to the large shareholder a number of shares contingent upon the offers made by the companies. To show this, let us continue with the above set-up, but let the government employ a sealed bid auction rather than the English auction from the previous example (in the general solution to the model, we will show that each of these mechanisms is the best possible mechanism for its corresponding case). In the sealed auction, each bidder submits a bid secretly. If all the bids are lower than 104.5, then the winner is randomly chosen among the bidders and gets 50% of shares, paying the price 89.5; if the highest bid is bigger or equal to 104.5, then the highest bidder wins, pays an amount equal to his bid and gets 65% of shares. Moreover, the loser gets a transfer $t = 0.5$ (this is not a necessary characteristic of the optimal mechanism but it simplifies the numerical example).

Given this mechanism there exists a continuum of equilibria in which company 1 bids $b_1 \in [0, 104.5)$ and company 2 bids $b_2 = 104.5$. Let us first check that this is an equilibrium. If company 1 bids $b_1 \in [0, 104.5)$, given the strategy of company 2, it always loses and therefore it obtains a payoff of 0.5. If it deviates, the best it can do is to bid $b_1 = 104.5 + \varepsilon$. In such cases, it always wins 65% of the shares and pays its bid. The expected payoff is then $105 - b_1 < 0.5$. Thus, company 1 has no incentive to deviate from its original strategy.

Let us now check the strategy of company 2. Company 2 of course has no incentive to bid higher than 104.5, since it obtains a negative surplus if it wins. Moreover, if it bids $b_2 < 104.5$, with probability $\frac{1}{2}$ it wins and has a surplus of -4.5, while with probability $\frac{1}{2}$ it loses and receives a transfer of 0.5. Therefore, the expected payoff is negative.

Given these strategies, the government sells 65% shares to company 2 and its total payoff is $R = 60.25$, which is higher than the optimum in the previous case. Thus, the government is better off with this mechanism than the previous one in which α was fixed prior to the auction at $\frac{2}{3}$. Essentially, with this more sophisticated mechanism, the government is still able to attract the most efficient buyer (company 2) but uses less shares than in the previous case.

The allocation of shares depending on the bids is represented in Figure 1. Three features of this new mechanism are worth noticing. First, when all the bids are low, the winner is randomly chosen and the payment is fixed. When the highest bids are high enough, instead, the mechanism looks like a sealed bid auction. Second, the number of shares α to be sold is a non-decreasing function of the winning bid. Later, we will show that these features are optimal for a class of situations. Finally, notice that company 2 wins but has zero surplus, while company 1 loses and has a positive expected payoff. In the general solution of the model we show that the expected profits of the bidders decrease as v_i increases.

4. The model

In this section we introduce the formal model and characterize the government's problem. In order to make the model tractable and to obtain better intuitions, we now assume that there is a linear relationship between v_i and B_i, i.e.:[8]

$$B_i = \bar{B} - \beta v_i. \tag{1}$$

[8] More precisely, we do not need a linear relationship, but simply a relationship $B_i = h(v_i)$, with $h' < 0$. In Section 6 we discuss a more general situation in which the government does not know exactly the relationship between v_i and B_i.

Empirical studies (see Barclay and Holderness (1989)) show that in general β is substantially lower than 1. We will therefore assume that $\beta < 1$.[9]

Given the linear relationship between v_i and B_i, the willingness to pay of a buyer, i, who receives a fraction α of the company can be re-written as

$$w_i = \alpha v_i + B_i = \bar{B} + (\alpha - \beta) v_i.$$

If $\alpha(v_i)$ is constant (or chosen *ex ante*), then $\frac{\partial w_i}{\partial v_i} = \alpha - \beta$. It is easy to show that if α is chosen *ex ante*, the optimal α is either β or $\underline{\alpha}$, depending on the value of the parameters. The intuition is simply that increasing α is costly and the government will do it only if it will enable it to end up with a more efficient buyer. For any α lower than β the winner of the auction will always be the less efficient company. Then there is no incentive for the government to sell more than $\underline{\alpha}$ shares. To attract the most efficient company it is enough that α is slightly higher than β and the government has no incentive to increase it even more.[10]

If the government has the option to make α contingent on the declared value v_i, then $\frac{\partial w_i}{\partial v_i} = \alpha_i - \beta + \alpha_i' v_i$. Thus, if the government wishes to attract the buyer who maximizes the value of the shares, it does not have to set $\alpha \geq \beta$. If the number of shares sold increases with the winning bid, the government achieves the same result by selling fewer shares.

The government does not know any of the values v_i and each foreign company knows only its own v_i, but both government and companies know that each v_i is drawn independently from the same distribution function $F(\cdot)$ over the interval $[0, \bar{v}]$, with density $f(\cdot)$. If $v = (v_j)_{j \in N}$, and $v_{-i} = (v_j)_{j \in N, j \neq i}$, we can define

$$G(v) \equiv [F(v_j)]^N$$

and

$$G_{-i}(v_{-i}) \equiv [F(v_j)]^{N-1}$$

with corresponding densities $g(v)$ and $g_{-i}(v_{-i})$.

Before continuing, let us discuss some underlying assumptions. First, we are assuming that the values v_i's are independent private values. Surely the value of a firm, consisting of discounted future profits, depends in part upon common elements which will not vary with the choice of controlling shareholder (for example, future exchange rates, real wages and other macroeconomic factors). However, different strategic plans may result in completely different and independent values. In general,

[9] Since we will prove that $\alpha^*(v_i) < \beta$, assuming $\beta < 1$ allows us to disregard the case in which there is an upper bound ($\alpha = 1$) to α. The analysis could however be modified to take that into account.

[10] For a detailed discussion and proof of this result, see Cornelli and Li (1994).

if the value of a domestic firm is mainly determined by common factors such as the ones mentioned above, then to find the right buyer is not an issue. In this case, only revenues matter, since efficiency does not depend on the controlling firm. Our mechanism, then, is particularly useful when the controlling party may have a strong impact on the firm's value, and therefore the government cares about who has the control of the firm, not only about revenues. These will be therefore the cases in which the variation of the value of the firm due to a change of control is far greater than the variation of the value of the firm across different future scenarios.

Finally, we are assuming that the underlying distribution of random variables is common knowledge. One way to justify our assumption could be that the government, before proceeding with the privatization, collects information (may be through consultants) and therefore has the same information as the other potential buyers.

The optimal selling procedure

The problem of the government is to design an optimal scheme which maximizes its objective function. By the Revelation Principle, we can restrict ourselves to studying only direct revelation mechanisms. Let $\tilde{v}$ be the vector of announced values, then $p_i(\tilde{v})$ is the probability that buyer i gets control; $\alpha_i(\tilde{v})$ is the proportion of shares buyer i obtains if he obtains control and $t_i(\tilde{v})$ is the amount he has to pay.

The expected payoff to a large buyer i with value v_i, who declares $\tilde{v}_i$ is

$$U_i(v_i, \tilde{v}_i) = \int_{V_{-i}} \left\{ \left[(\alpha_i(\tilde{v}_i, v_{-i}) - \beta)\, v_i + \tilde{B} \right] p_i(\tilde{v}_i, v_{-i}) - t_i(\tilde{v}_i, v_{-i}) \right\} g_{-i}(v_{-i}) dv_{-i}. \tag{2}$$

The government's objective function is:

$$\int_V \left[\lambda \sum_i t_i(v) + (1-\lambda) \sum_i [1 - \alpha_i(v)] v_i p_i(v) \right] g(v) dv. \tag{3}$$

The government maximizes its objective function with respect to α, p and t subject to several constraints. The individual rationality constraint:

$$U_i(v_i, v_i) \geq 0,\ \forall i \in N,\ \forall v_i \in [0, \bar{v}]; \tag{4}$$

the incentive compatibility constraint:

$$U_i(v_i, v_i) \geq U_i(v_i, \tilde{v}_i),\ \forall \tilde{v}_i \in [0, \bar{v}],\ \forall i \in N,\ \forall v_i \in [0, \bar{v}] \tag{5}$$

and two other constraints:

$$\sum_i p_i(v) \le 1; \tag{6}$$

$$\underline{\alpha} \le \alpha_i(v) \le 1. \tag{7}$$

In Appendix A1 we derive the first and second order conditions of the maximization implied by constraint (5) and, following Myerson (1981), we utilize the first order conditions to transform the objective function of the government into the following:

$$\int_V \Big\{ \sum_i \Big[v_i \left[\lambda(1-\beta) + (1-2\lambda)(1-\alpha_i(v))\right] + \lambda\bar{B} - \lambda\left(\alpha_i(v) - \beta\right) \frac{1-F(v_i)}{f(v_i)} \Big] p_i(v) \Big\} g(v)dv - \lambda \sum_i U_i(0,0). \tag{8}$$

Since all the potential buyers are risk neutral, there is no advantage for the government to choose randomized outcomes.[11] Therefore, each p_i will be equal to 0 or 1. In the same way it is possible to prove that α_i is independent of v_{-i}. Recall that α_i is the number of shares buyer i obtains if he wins. Hence, α_i is defined only with respect to those vectors v such that i is a winner. Then, making α_i dependent on v_{-i} is equivalent to adding a randomization to α_i. From now on, we assume that α_i depends only on v_i. To simplify the notation, we can then drop the subscript and write only $\alpha(v_i)$.

We can now simplify the notation and summarize the problem in the following lemma:

Lemma 1: *Define*

$$R(v_i, \alpha(v_i)) \equiv v_i[\lambda(1-\beta) + (1-2\lambda)(1-\alpha(v_i))] + \lambda\bar{B} - \lambda\left(\alpha(v_i) - \beta\right)\frac{1-F(v_i)}{f(v_i)} \tag{9}$$

and

$$P(v_i) \equiv \int_{V_{-i}} p_i(v) g_{-i}(v_{-i}) dv_{-i} \tag{10}$$

which is the (unconditional) probability that bidder i wins the control right, given that its valuation is v_i.

The government's problem is to choose α and p_i in order to maximize the objective function:

$$\int_V \sum_i R(v_i, \alpha(v_i)) p_i(v) g(v) dv - \lambda \sum_i U_i(0,0), \tag{11}$$

[11] See Maskin and Riley (1990).

subject to the following constraints:

$$U_i(v_i, v_i) \geq 0,\ \forall i \in N,\ \forall v_i \in [0, \bar{v}];^{12} \tag{12}$$

$$\alpha'(v_i)P(v_i) + [\alpha(v_i) - \beta]\, P'(v_i) \geq 0 \tag{13}$$

(which are the second order conditions derived in the appendix A1);

$$\sum_i p_i \leq 1, \quad 0 \leq p_i \leq 1; \tag{14}$$

$$\underline{\alpha} \leq \alpha \leq 1. \tag{15}$$

Constraint (13) holds for all v_i at which $\alpha(v_i)$ and $P(v_i)$ are differentiable.[13]

If we compare the problem with a standard optimal auction, the government now has one more instrument with which to induce the bidder to reveal his true willingness to pay. An increase in α generates more revenue from the auction and may attract more efficient bidders. On the other hand, an increase in α reduces the value of the unsold part of the firm. However, the government is more concerned with value than with the revenue (i.e. $\lambda \leq \frac{1}{2}$).[14] Therefore, if we ignore its potential function to screen different bidders, α should not be higher than $\underline{\alpha}$. To see this, notice that, since we assumed that $0 \leq \lambda \leq \frac{1}{2}$,

$$\frac{\partial}{\partial \alpha}\left(\int_V \sum_i R(v_i, \alpha(v_i)) p_i(v) g(v) dv\right) = \int_V \sum_i R_\alpha(v_i, \alpha(v_i)) p_i(v) g(v) dv \leq 0, \tag{16}$$

where

$$R_\alpha = (2\lambda - 1)v_i - \lambda \frac{1 - F(v_i)}{f(v_i)} < 0.$$

[12] One remark on the individual rationality constraint, (12), is due here. In the standard literature on auctions, it can be showed at this stage that $U(v_i, v_i)$ is monotonic increasing, therefore by setting $U_i(0,0) = 0$ it is possible to take care of constraint (12). In our model, however, we do not know yet whether $U_i(v_i, v_i)$ is increasing or decreasing with v_i, nor whether it is monotonic. Fortunately, when we will look at the optimal mechanism, we will be able to determine that $U_i(v_i, v_i)$ is monotonic decreasing in cases 1 and 2 and monotonic increasing in case 3. We will then be able to use the same logic and rescale $U_i(0,0)$ to take care of constraint (12).

[13] To be precise, condition (13) is only a necessary but not sufficient condition for the incentive compatibility constraint condition to hold. It only guarantees that truth telling is locally optimal for bidders, rather than globally. Thus, solutions to the problem in Lemma 1 do not necessarily solve the government's problem. However, in what follows we will check that our solutions satisfy the sufficient condition.

[14] Moreover, since the government does not know the private information v_i of each company, it will not be able to extract all the rents of the private companies. Therefore, as α increases, the value part of the objective decreases, while the revenues increase less than proportionally.

Thus $\alpha = \underline{\alpha}$ is the solution of the unconstrained problem. However, this solution often violates constraint (13). The intuition is quite simple: the optimum for the government would be to attract the most efficient buyer by sacrificing the minimum number of shares. However, if the number of shares sold is low, the buyer willing to pay more will often be the less efficient one. Only by selling a number of shares higher than the minimum, can the government discriminate among the different buyers.

When the second order condition (13) is binding, the optimal α must be given by the differential equation:

$$\alpha'(v_i)P(v_i) + [\ \alpha(v_i) - \beta\ ]\ P'(v_i) = 0.$$

In the standard literature on optimal auctions, if the unconstrained solution violates the second order condition (the monotonicity condition), a "bunching" solution is applicable. That is, if all announced valuations are in a certain range, the seller picks the winner randomly.[15] This is equivalent to setting $P(v_i)$ to be a constant, instead of an increasing function, in order to satisfy the monotonicity condition. In our case, when the unconstrained solution $\alpha = \underline{\alpha}$ violates the second order condition (13), there are two instruments that the government can modify to satisfy (13): $\alpha(v_i)$ and $P(v_i)$. In addition to modifying $P(v_i)$, the government can also change α in order to satisfy the constraint. Finding the optimal selling procedure in this case is to find the right balance between these two instruments.

Constraint (13) is written only for the case in which $\alpha(v_i)$ and $P(v_i)$ are differentiable. In Appendix A3 we will derive the equivalent of condition (13) when $\alpha(v_i)$ and $P(v_i)$ are discontinuous at a point v_0. In line with the literature, we restrict attention to mechanisms $\alpha(v_i)$ and $P(v_i)$ which are piece-wise differentiable.[16]

5. Three Cases

We will focus on three cases that span a spectrum of the optimal privatization procedures. These cases correspond to important economic environments and have clear interpretations. The first case corresponds to a situation in which the efficiency objective is too costly to achieve. In the second case the government finds it optimal to screen among potential buyers in order to achieve the efficiency objective. In the third case, the government faces a less difficult problem and can achieve efficiency at a low cost. We distinguish these three cases on the basis of the monotonic properties of $R(v_i, \alpha)$, the transformed objective function defined in equation (9). For simplicity, let us assume that the hazard rate is monotonically increasing with v_i: although, strictly speaking, we do not need

[15]See Guesnerie and Laffont (1984) and Maskin and Riley (1990).

[16]See, among others, Maskin and Riley (1984) and (1990)

this assumption, it allows us to characterize such cases in terms of the parameters λ and β, since $\frac{\partial^2 R}{\partial v_i \partial \beta} < 0$ and $\frac{\partial^2 R}{\partial v_i \partial \lambda} < 0$.[17] In the first two cases $\beta > \underline{\alpha}$, in the third $\beta < \underline{\alpha}$.

5.1. *The case of $R(v_i, \underline{\alpha})$ monotonically decreasing in v_i*

The assumption that $R(v_i, \underline{\alpha})$ is monotonically decreasing with v_i is more likely to be satisfied when λ and β are high. The mechanism characterized in this section is therefore optimal when the government cares relatively less about efficiency—for example, it is in urgent need to collect some funds—and the trade-off between private benefit of control and efficiency is very sharp. When the trade-off is sharp the government, to achieve efficiency, should offer a large α. This may prove to be too costly and the government may instead prefer to maximize the revenue component of its objective function by selling $\underline{\alpha}$ shares. In this case, the optimal selling procedure is quite simple and is characterized in the following proposition. The proof is given in Appendix A2.

Proposition 1: *When $R(v_i, \underline{\alpha})$ is a monotonically decreasing function of v_i, the government will give $\underline{\alpha}$ shares to the firm declaring the lowest v_i.*

Proof: See Appendix A2.

Clearly, if the government had chosen α *ex ante* the same solution would obtain. The government obtains nothing by making α depend on the reported valuation. In order to implement this solution, then, the government could commit to selling the smallest possible share in the firm $\underline{\alpha}$, and allocate this share to the highest bidder in an English or Vickrey auction.

5.2. *The case of $R(v_i, \alpha)$ monotonically increasing in v_i for any α*

The mechanism discussed in this section is the optimal mechanism to use when $R(v_i, \alpha)$ is monotonically increasing with v_i. In fact, the monotonicity of $R(v_i, \alpha)$ is only a sufficient condition for the optimality of this mechanism, not a necessary one. However, we will examine this mechanism solely in the context of an $R(v_i, \alpha)$ function that is monotonic in v_i. This assumption is more likely to be satisfied when λ and β are low. The mechanism characterized in this section will therefore be optimal when the revenue objective is not very important and the trade-off between private benefit of control and the value of the firm is not too sharp. In other words, the government has an incentive to screen among buyers, since the cost of selling additional shares is more than compensated by the increase in efficiency.

[17] Monotonicity of the hazard rate is a standard assumption in the literature of optimal auctions and it is satisfied by most of the typical distributions.

As we showed in the numerical example of Section 3, one possibility is for the government to commit *ex ante* to selling β shares at the auction. This will guarantee that the buyer will be the most efficient company. However, in the next proposition we derive the optimal mechanism and we show that the government can do better by not committing *ex ante* to a given α. Instead, the actual number of shares sold is made contingent on the declared valuations and it is always lower than β.

Proposition 2: *Assume that $R(v_i, \alpha)$ is monotonically increasing with v_i for any constant α. The optimal privatization scheme is two-fold. There always exists a $\hat{v} > 0$ such that, for any $v_i \in [0, \hat{v}]$, $\alpha^*(v_i) = \underline{\alpha}$ and $P^*(v_i)$ is constant, while, for any $v_i \in [\hat{v}, \bar{v}]$, $P^*(v_i) = [F(v_i)]^{n-1}$ and*

$$\alpha^*(v_i) = \beta - \frac{c_0}{P^*(v_i)}, \tag{17}$$

where $c_0 > 0$, so that α is always less than β.

Proof: See Appendix A3.

The optimal scheme is illustrated in Figure 2. In Appendix A3 it is also shown that it is never optimal to set reservation prices. This implies that, when only low v_i's are declared, the government only sells $\underline{\alpha}$ shares and randomly chooses the buyer. If at least one bidder declares a $v_i > \hat{v}$, the government assigns the control right to the buyer declaring the highest v_i and sells him $\alpha^*(v_i)$ shares, given by equation (17), which is increasing with v_i. In all cases, $\alpha^*(v_i) < \beta$.

From equation (A12), the expected payments are the following: if a buyer declares a valuation $v_i \leq \hat{v}$, then

$$\int_{V_{-i}} t_i(v) g_{-i}(v_{-i}) dv_{-i} = \frac{1}{N}[F(\hat{v})]^{n-1}\,[\bar{B} - \bar{v}(\beta - \underline{\alpha})]$$

if instead he declares a valuation $v_i > \hat{v}$, then

$$\int_{V_{-i}} t_i(v) g_{-i}(v_{-i}) dv_{-i} = \bar{B}[F(v_i)]^{n-1} + (\beta - \underline{\alpha})\frac{1}{N}[F(\hat{v})]^{n-1}(2\hat{v} - \bar{v})$$

In order to implement this solution, the government could adopt the following indirect mechanism. All the foreign companies make a bid. If all the bids are below a predetermined level, then the minimum number of shares $\underline{\alpha}$ is given to one of them at random. If at least one bid is above that level, then the highest bidder wins the auction and obtains more shares the higher is his bid (according to equation (17)). This last aspect of the mechanism is crucial: the number of shares to be sold is not fixed in advance, but is determined endogenously from the outcome of the auction. It is easy to see that this is the continuous version of the mechanism described in Figure 1, where 65% of the shares were sold instead of 50%, as long as the winning bid was higher than 104.5.

The fact that α is determined endogenously and depends on the winning bid serves as an important screening device to induce truth telling from the bidders so that the government is able to choose the most efficient company. If a company makes a higher bid, it obtains more shares and a higher probability of winning but the price also increases more than proportionately. In this way, bidders with high v_i would not make a low bid, since they are attracted by the high α which increases their willingness to pay $\alpha v_i + B_i$. Also, they are attracted by the higher probability to win. At the same time, a bidder with low v_i would not bid high, since its low v_i cannot make its willingness to pay $\alpha v_i + B_i$ increase as rapidly as the price.

5.3. The Case of $\beta < \underline{\alpha}$

In this case the trade-off between benefits of control and the total public value of the firm is rather flat. Thus, by offering the minimum proportion of shares, the government can already screen among buyers. The rest of the issue is how to choose the winner. The standard optimal auction literature can apply here.

Proposition 3: *If $\beta < \underline{\alpha}$, the optimal privatization scheme is to sell $\underline{\alpha}$ shares to the buyer with the highest v_i, if $v_i \geq v^*$, where v^* is defined as $R(v^*, \underline{\alpha}) = 0$.*

Proof: The proof is standard, once we notice that in such a case $R(v_i, \underline{\alpha})$ is monotonic increasing with v_i and therefore constraint (13) is never binding. Also, notice that when $\underline{\alpha} > \beta$, $U_i(v_i, v_i)$ is monotonic increasing with v_i. Thus, the individual rationality condition (12) can be taken care of by setting $U_i(0,0) = 0$ as in the standard auction literature.

Q.E.D.

An optimal mechanism is for the government to sell $\underline{\alpha}$ shares in a Vickrey or an English auction, with the reservation price given by $\bar{B} + (\underline{\alpha} - \beta)v^*$. Therefore, the optimal mechanism is very simple and easy to use. Notice that in this case, the benefits of control do not complicate the design of privatization and the government can choose the most efficient buyer.

6. Uncertainty about β

Throughout the paper we have assumed that the values of v_i and B_i are linked through a relationship which is common knowledge. One possible objection to the latter assumption, however, comes from the fact that the government may not know the shape of this frontier exactly. In this section we address this problem. Deriving the optimal mechanism in such a case is very complex and beyond the scope of this paper. However, we argue that the mechanism suggested in our paper still works quite well and in particular it dominates the obvious and simple alternative: to choose *ex ante* the number of shares and then conduct an English or Vickrey auction.

For simplicity, we consider a special case: the government knows that the relationship between v_i and B_i is linear, but β could take two values —$\beta_1 < \beta_2$. The government does not know which is the true value of β. To focus on the most interesting case, let us assume that the true $\beta > \underline{\alpha}$.[18] We show that even in presence of uncertainty the government can always do better with our mechanism than with a Vickrey auction with α chosen *ex ante*.

Assume first the government commits *ex ante* to selling α shares using an English auction. Only three values of α could possibly be optimal: $\underline{\alpha}$—if it decides not to attract the most efficient company—β_1 or β_2—depending on the prior about the true β. We proceed in the following way: we assume that the government has chosen one of these numbers and then we show that the optimal mechanism derived in this paper, using the same β, can do better.

First of all, if the government decides it is not worthwhile to attract the most efficient buyer, the two mechanisms coincide and there is no problem.[19] Let us look instead at the case in which the government decides to sell $\beta_i > \underline{\alpha}$ shares and compare the result of an English auction of β_i shares with the result of our mechanism. If the true $\beta = \beta_2$ and the government believes that $\beta = \beta_1$ and set $\alpha = \beta_1$, then the simple scheme ends up choosing the buyer with the lowest v_i. The mechanism described in Proposition 2 may or may not choose the buyer with the highest v_i. However, under this mechanism, a smaller share of the firm is sold than under the simple Vickrey auction, and therefore secures a superior outcome for the government.

If the true $\beta = \beta_1$ and the government believes that $\alpha = \beta_2$, then the simple scheme ends up with the highest v_i by selling β_2 shares. However, our more sophisticated scheme in Proposition 2 based on $\beta = \beta_2$ sells strictly fewer shares than β_2 and also chooses the buyer with the highest v_i. Note that the incentive compatibility constraints will still be satisfied if the government constructs the mechanism on the basis of a β higher than the true one. To see this, assume the true $\beta = \beta_1$ and the government chooses to sell according to the mechanism given in Proposition 2 with $\beta = \beta_2$. This means he would choose $P^*(v_i) = [F(v_i)]^{n-1}$ and

$$\alpha^*(v_i) = \beta_2 - \frac{c_0}{[F(v_i)]^{n-1}}.$$

Constraint (13) would therefore become:

$$(\beta_2 - \beta_1)P'(v_i) \geq 0$$

[18] If this is not true, we know from Section 5 that an English auction selling $\underline{\alpha}$ shares is optimal.

[19] In Section 5.1 we showed that if the government chooses not to attract the most efficient buyer, the optimal mechanism is a Vickrey or English auction of $\underline{\alpha}$ shares.

which is clearly satisfied. Therefore the mechanism would still work and attract the most efficient company by selling fewer shares.[20]

The upshot of the above discussion is the following. Although it is unrealistic to assume that the government knows the precise relationship between v_i and B_i, our mechanism performs quite well as long as the government lacks only a little information. In particular, we have shown that, if the relationship can be summarized by a single parameter, the government continues to benefit from using this mechanism, even if there is uncertainty around the value of the parameter. While we do not identify the optimal mechanism for this scenario, the one we propose will still perform better than the simple mechanism.

7. Conclusions

In this paper we have addressed the issues arising in privatization of state enterprises, when large foreign investors are the potential buyers. Since large foreign investors can enjoy excessive private benefit of control at the expense of domestic shareholders, not all foreign investors are desirable shareholders of privatized state enterprises.

Depending on the government preferences between efficiency and revenues and on the trade-off between the value of the privatized firm and the private benefit of control, we have derived some different optimal mechanisms. When the trade-off is either very flat or very sharp, then a simple English auction is optimal and the government should only sell $\underline{\alpha}$ shares. The difference is that in the first case the government will be able to attract the most efficient firm, while in the second the government would only maximize revenue. If the trade-off ratio is in between the above two cases, then the government should adopt a two-fold scheme. When all bids are low, the government randomly chooses the winner and sells only the minimum number of shares. When there is at least one high bid, the government picks the highest bidder and gives him a number of shares positively dependent on the winning bid. In this case, the government is better off with the number of shares being chosen endogenously, rather than committing to selling a given number of shares *ex ante*. Notice that such a scheme is quite simple to implement.

Throughout the paper we assumed that buyers were risk neutral. In general, foreign companies will be risk averse. When we relax such an assumption we know from Maskin and Riley (1984) that an open English auction is better than a sealed bid auction. Therefore, the scheme suggested here should be modified to allow for successive rounds of public bids, as in an open English auction, so that

[20] One exception arises when all announced v_i's are low and the government randomly chooses the winner. However, this is an optimal choice of the government: the cost of not choosing the highest v_i is compensated by the benefit of selling fewer shares. When the true β is not too far away from the chosen one, such a cost should still be compensated by the benefit. Thus, a qualification for this exception is that the chosen β is comfortably close to the true one.

each foreign company could see the competitors' bids. More generally, if we relax the assumptions of risk neutrality and common knowledge of the underlying distribution of public values, one can imagine that, prior to the auction, the government could adopt a procedure like the "book building", which is increasingly common in international initial public offerings and in privatizations in western countries. In such a case, the investment bank in charge of the sale could consult its clients and the potential buyers prior to the auction in order to form a clearer idea of the value of the firm under various buyers could be. Once such information has been collected, the investment bank may form an idea about the underlying distribution and it can design the auction on this basis.

There are two potential extensions of the paper's framework and approach. First, privatization of public firms in mature market economies can be similarly examined. The basic points of this paper are also relevant in these countries, since the government cares both the future value of the privatized firm and the sales revenue. Second, our analyses can be extended to corporate control issues in market economies. Many times, multiple investment groups are competing for the control right of a corporation. The decision of the corporate board is similar to that of a privatization government. Both also share similar concerns with the private benefits of control. Moreover, manipulating the number of shares that go with the control right is equivalent to departing from the structure of one-share-one-vote (see Grossman and Hart, 1988 and Harris and Raviv, 1988). Thus, our framework can be used to analyze the voting structure of the firms' securities which should be positioned for the best interest of existing stakeholders.

APPENDIX

A1. Derivation of the first and second order condition.

The incentive compatibility constraint (5) can be expressed as:

$$v_i = \arg\max_{\tilde{v}_i} \int_{V_{-i}} \left\{ \Big[\alpha_i(\tilde{v}_i, v_{-i})v_i + \bar{B} - \beta v_i\Big] p_i(\tilde{v}_i, v_{-i}) - t_i(\tilde{v}_i, v_{-i}) \right\} g_{-i}(v_{-i}) dv_{-i}. \tag{A1}$$

Define

$$U_i(v_i, \tilde{v}_i) \equiv \int_{V_{-i}} \left\{ \Big[\alpha_i(\tilde{v}_i, v_{-i})v_i + \bar{B} - \beta v_i\Big] p_i(\tilde{v}_i, v_{-i}) - t_i(\tilde{v}_i, v_{-i}) \right\} g_{-i}(v_{-i}) dv_{-i}. \tag{A2}$$

Since $x_i(v_i) = v_i$, assuming differentiability, by envelope theorem

$$\frac{dU_i}{dv_i}(v_i, v_i) = \int_{V_{-i}} \Big[\alpha_i(v_i, v_{-i}) - \beta\Big] p_i(v_i, v_{-i}) g_{-i}(v_{-i}) dv_{-i}. \tag{A3}$$

Re-integrating it, we get:

$$U_i(v_i, v_i) = \int_0^{v_i} \int_{V_{-i}} \Big[\alpha_i(x, v_{-i}) - \beta\Big] p_i(x, v_{-i}) g_{-i}(v_{-i}) dv_{-i} dx + U_i(0,0). \tag{A4}$$

Comparing the expression for $U_i(v_i, v_i)$ in (A4) and its definition in (A2) and solving for the transfers we obtain:

$$\int_V t_i(v) g(v) dv = -U_i(0,0) \; + \; \int_V \Big[\alpha_i(v)v_i + \bar{B} - \beta v_i\Big] p_i(v) g(v) dv \; +$$

$$- \int_{v_{-i}} g_{-i}(v_{-i}) \int_{v_i} g_i(v_i) \int_0^{v_i} \Big[\alpha_i(x, v_{-i}) - \beta\Big] p_i(x, v_{-i}) dx dv_i dv_{-i}.$$

Integrating by parts and using the independence of the distribution of v_i's, such expression can be transformed into:

$$\int_V t_i(v) g(v) dv = \int_V \left\{ \; [\alpha_i(v)v_i + \bar{B} - \beta v_i] \; - \; [\alpha_i(v) - \beta] \frac{1 - F_i(v_i)}{f_i(v_i)} \right\} p_i(v) g(v) dv - U_i(0,0). \tag{A5}$$

Substituting (A5) into (3) we obtain equation (8). Notice that using equation (A4) and the expression for the transfers we can write the expected utility of a company of type v_i declaring $\tilde{v}_i$ as

$$U_i(v_i, \tilde{v}_i) = P(\tilde{v}_i)\left[\alpha(\tilde{v}_i) - \beta\right](v_i - \tilde{v}_i) + \int_0^{\tilde{v}_i} \left[\alpha(s) - \beta\right] P(s) ds + U_i(0,0). \tag{A6}$$

which will become useful later.

The second order condition of the maximization in (A1) is:

$$\frac{\partial^2 U_i(v_i, \tilde{v}_i)}{\partial \tilde{v}_i{}^2} |_{\tilde{v}_i = v_i} \leq 0.$$

Recall the first order condition:

$$\frac{\partial U_i(v_i, \tilde{v}_i)}{\partial \tilde{v}_i} |_{\tilde{v}_i = v_i} \equiv 0.$$

Differentiating this first order condition on both sides with respect to $\tilde{v}_i$, we have

$$\frac{\partial^2 U_i(v_i, \tilde{v}_i)}{\partial v_i \partial \tilde{v}_i} |_{\tilde{v}_i = v_i} + \frac{\partial^2 U_i(v_i, \tilde{v}_i)}{\partial \tilde{v}_i{}^2} |_{\tilde{v}_i = v_i} = 0.$$

Therefore, a second order condition can be found as:

$$\frac{\partial^2 U_i(v_i, \tilde{v}_i)}{\partial v_i \partial \tilde{v}_i} |_{\tilde{v}_i = v_i} \geq 0.$$

which turns out to be

$$\int_{V_{-i}} \left\{ \frac{\partial \alpha_i(v)}{\partial v_i} p_i(v) + \left[\alpha_i(v) - \beta \right] \frac{\partial p_i(v)}{\partial v_i} \right\} g_{-i}(v_{-i}) dv_{-i} \geq 0, \quad \forall i \in N, \; \forall v_i \in [0, \bar{v}],$$

which is the same as equation (13) given the definition of $P(.)$. Notice that this second order condition is simply a more complex version of the normal monotonicity condition in conventional auction designs.

A2. The Proof of Proposition 1

From equation (16), if we ignore constraint (13) the optimal choice is $\alpha = \underline{\alpha}$. Since $R(v_i, \underline{\alpha})$ is, by assumption, decreasing in v_i, setting $p_i = 1$ for the lowest v_i is the policy that maximizes the objective function. Since such a policy implies $P'(v_i) < 0$, constraint (13) is indeed satisfied. From (9), $R(v_i, \underline{\alpha})$ is always positive, so no reservation prices are needed. Applying the envelope theorem to the incentive compatibility constraint (5), we have:

$$\frac{dU_i(v_i, v_i)}{dv_i} = [\alpha_i(x) - \beta] P(x). \tag{A7}$$

Therefore,

$$U_i(v_i, v_i) = \int_0^{v_i} [\alpha_i(x) - \beta] P(x) dx + U_i(0,0). \tag{A8}$$

Given the optimal choice of p_i and α, the expected utility of a bidder is monotonic decreasing with v_i and $\overline{v}$ has the lowest expected payoff (in other words, the individual rationality constraint is binding only at $\overline{v}$). Therefore, if the government sets

$$U_i(0,0) = (\beta - \underline{\alpha}) \int_0^{\overline{v}} [1 - F(x)]^{n-1} dx,$$

then the individual rationality constraint is satisfied. We can now check that the global incentive compatibility condition is also satisfied by the optimal scheme, i.e. truth-telling is indeed a global optimum strategy for each bidder. If we substitute the optimal scheme in equation (A6), we obtain

$$U_i(v_i, \tilde{v}_i) = (1 - F(\tilde{v}_i))^{n-1} [\underline{\alpha} - \beta] (v_i - \tilde{v}_i) - (\underline{\alpha} - \beta) \int_{\tilde{v}_i}^{\overline{v}} (1 - F(s))^{n-1} ds \tag{A9}$$

Truth-telling is an equilibrium if

$$U_i(v_i, v_i) \geq U_i(v_i, \tilde{v}_i), \forall v_i, \tilde{v}_i.$$

If $\tilde{v}_i < v_i$ this condition becomes

$$\int_{\tilde{v}_i}^{v_i} (1 - F(x))^{n-1} dx \geq (1 - F(\tilde{v}_i))^{n-1} (v_i - \tilde{v}_i)$$

which is always true since $1 - F(x)$ is a non-increasing function. The same can be shown for $\tilde{v}_i > v_i$.

A3. Proof of Proposition 2

We give here only an outline of the proof. Details can be found in Cornelli and Li (1994).

Let us first prove that if $R(v_i, \alpha)$ is monotonic increasing with v_i for any α constant, then $\alpha^*(v_i) < \beta$ for any v_i.

Step 1

In what follows it will be convenient to use a transformed form of the government objective function. Note that the distributions of v_i's are independent and α—and therefore R—is a function of v_i only. Also, all players are, *ex ante*, symmetric. Thus, using the definition of $P(v_i)$ given in equation (10), the objective function of the government can be rewritten as

$$n \int_0^{\overline{v}} R(v_i, \alpha(v_i)) P(v_i) f(v_i) dv_i. \tag{A10}$$

Step 2

The first problem that arises is that the optimal mechanism may have discontinuities. At each discontinuous point, we cannot use condition (13) to check the incentive compatibility constraint. The following lemma gives us a more general condition which allows for discontinuities.

Lemma A.1: *Suppose that $\alpha(v_i)$ and $P(v_i)$ are discontinuous at a point v_0, i.e. $\alpha(v_0^+) \neq \alpha(v_0^-)$ or $P(v_0^+) \neq P(v_0^-)$. Then the second order condition of the incentive compatibility constraint at the point v_0 becomes*

$$P(v_0^-)(\alpha(v_0^-) - \beta) - P(v_0^+)(\alpha(v_0^+) - \beta) \leq 0. \tag{A11}$$

Proof: Notice that to the left and to the right of the point v_0, $\alpha(v_i)$ is continuous and therefore the usual incentive compatibility constraint holds in this region. Moreover, all the steps used to arrive at expression (8) will hold for these intervals of v_i, since there is no non-differentiability problem. In particular, the optimal expected transfers can be expressed (as in Myerson, 1981) as

$$\begin{aligned} \int_{V_{-i}} t_i(\tilde{v}_i, v_{-i}) g_{-i}(v_{-i}) dv_{-i} &= -U_i(0,0) + \\ \int_{V_{-i}} \Big\{ \left[(\alpha(\tilde{v}_i) - \beta)\, \tilde{v}_i + \bar{B} \right] p_i(\tilde{v}_i, v_{-i}) &- \int_0^{\tilde{v}_i} [\alpha(s) - \beta]\, p_i(s, v_{-i}) ds \Big\}\, g_{-i}(v_{-i}) dv_{-i}. \end{aligned} \tag{A12}$$

and equation (A6) is still true.

Suppose that an individual with valuation $v_i = v_0 - \epsilon$ declares a value $\tilde{v}_i = v_0 + \epsilon$. His gain in doing so is

$$G = U_i(v_0 - \epsilon, v_0 + \epsilon) - U_i(v_0 - \epsilon, v_0 - \epsilon)$$

$$= P(v_0 + \epsilon) [\alpha(v_0 + \epsilon) - \beta] (-2\epsilon) + \int_{v_0 - \epsilon}^{v_0 + \epsilon} [\alpha(s) - \beta]\, P(s) ds$$

The second term in the last expression can be re-written as

$$\int_{v_0 - \epsilon}^{v_0} [\alpha(s) - \beta]\, P(s) ds + \int_{v_0}^{v_0 + \epsilon} [\alpha(s) - \beta]\, P(s) ds \tag{A13}$$

which, by Cauchy's theorem, is equal to,

$$[\alpha(\xi_1) - \beta]\, P(\xi_1)\epsilon + [\alpha(\xi_2) - \beta]\, P(\xi_2)\epsilon, \tag{A14}$$

where $v_0 - \epsilon \le \xi_1 \le v_0$ and $v_0 \le \xi_2 \le v_0 + \epsilon$. When $\epsilon \to 0$, $\xi_1 \to v_0^-$ and $\xi_2 \to v_0^+$. Therefore, if we define $P^+ \equiv P(v_0^+)$, $P^- \equiv P(v_0^-)$, $\alpha^+ \equiv \alpha(v_0^+)$ and $\alpha^- \equiv \alpha(v_0^-)$, then G/ϵ converges to

$$P^-(\alpha^- - \beta) - P^+(\alpha^+ - \beta). \tag{A15}$$

Therefore, we require that the expression above is non positive. Notice that if ϵ is negative, then G/ϵ is non-positive and P^+ and α^+ should be written as P^- and α^-. Hence, the expression above holds whether an individual declares a lower type or a higher type.

Q.E.D.

From now on, whenever we want to check the incentive compatibility constraint, we will use condition (13) if there are no discontinuities or condition (A11) if there is a discontinuity. **Step 3**

We can now show that the government will never offer a number of shares higher than β.

Lemma A.2: *$\alpha(v_i) > \beta$ for some v_i is never optimal.*

Proof: The sketch of the proof is the following. We analyze separately the discontinuous and continuous case. In both cases, we show that the government can always do better than setting $\alpha(v_i) > \beta$ since it can always set $\alpha(v_i) = \beta$ and leave the same $P(v_i)$, which remains incentive compatible.

We are now left with only two possibilities: $\alpha = \beta$ or $\alpha < \beta$. To show that $\alpha < \beta$ for all v_i's, we need first to prove that $R(v_i, \alpha^*(v_i))$ is monotonic increasing in v_i.

Step 4

Lemma A.3: *If $R(v_i, \alpha)$ is monotonic increasing with v_i for any α constant, then $R(v_i, \alpha^*(v_i))$ is also monotonic increasing in v_i. Moreover, when $\alpha = \alpha^*(v_i)$, constraint (13) (or (A11)) always holds with an equality at all v_is.*

Proof: The proof of Lemma 3 shows that it is never optimal for the government to increase the number of shares sold (as v_i increases) so fast that the function R becomes decreasing with v_i. Lemma 3 implies that constraint (13) (or (A11) if there is a discontinuity) is always binding.

Step 5

We can now show that the optimal α is indeed always less than β. Notice that one implication is that $U_i(v_i, v_i)$ is monotonic decreasing with v_i and $\underline{v}$ has the lowest payoff.

Proof: First, in any intervals where α is continuous and differentiable, either $\alpha < \beta$ everywhere or $\alpha \equiv \beta$. From the last lemma, in each such interval, constraint (13) holds strictly, i.e.,

$$\alpha'(v_i)P(v_i) + (\alpha(v_i) - \beta)P'(v_i) = 0,$$

which gives

$$\alpha(v_i) = \beta - \frac{c_0}{P(v_i)}, \tag{A16}$$

where c_0 is given by the initial condition. If in the beginning of the interval $\alpha(0) < \beta$, then c_0 is positive. But then, $\alpha(v_i)$ is bounded above by $\beta - c_0$. Therefore, we are left with only two possibilities: either $\alpha = \beta$ for the whole interval $(0, \bar{v})$ or α reaches β via a discontinuous point. Let us consider this second possibility and call such a point v_0, where $\alpha(v_i) < \beta$ for $v_i < v_0$ and $\alpha(v_i) = \beta$ for $v_i > v_0$. From the proof of the last lemma we know that (A11) holds strictly at v_0, i.e.

$$P(v_0^+)(\beta - \alpha^+) = P(v_0^-)(\beta - \alpha^-) = 0$$

which implies that $P(v_0^-) = 0$. However, this cannot be optimal, since in this region $\alpha < \beta$ and therefore $R(v_i) > 0$ and the government would have done better by setting P positive. Hence $\alpha = \beta$ is possible only if it is true over all the interval $[0, \bar{v}]$. But also in this case, the government can always set a lower initial condition and increase α so that the constraint is always satisfied. Therefore $\alpha = \beta$ is never optimal.

Q.E.D.

We can now derive the optimal mechanism $\{\alpha^*(v_i), P^*(v_i)\}$.

Step 6

The first step is to transform the problem into a tractable optimal control set-up. The following lemma shows that the optimal $\alpha^*(v_i)$ and $P^*(v_i)$ are linked by the same relationship for all the interval $[0, \bar{v}]$.

Lemma A.4: *Suppose that $R(v_i, \alpha)$ is monotonically increasing in v_i for any α constant and that $\alpha(v_i)$ and $P(v_i)$ represent the optimal choice of the government, then there exists a constant $c_0 > 0$ such that for all v_i,*

$$\alpha(v_i) = \beta - \frac{c_0}{P(v_i)}.$$

From previous lemmas, we know that (A16) must hold at all v_i where $\alpha(v_i)$ and $P(v_i)$ are differentiable. If in the whole range of $(0, \overline{v})$, $\alpha(v_i)$ and $P(v_i)$ are differentiable, then the second order condition will give the relationship in the lemma. What needs to be proved is the case where either $\alpha(v_i)$ or $P(v_i)$ are not differentiable at a point v_0. This can be done by contradiction using the incentive compatibility constraint from Lemma A.1 (A11).

Step 7

We now have to transform the constraints in order to write down the optimal control problem. We know that $\alpha^*(v_i) < \beta < 1$. In other words, the constraint $\alpha \leq 1$ is never binding. We can ignore this constraint from now on. The constraint $\alpha \geq \underline{\alpha}$ becomes:

$$\beta - \frac{c_0}{P(v_i)} \geq \underline{\alpha}. \tag{A17}$$

Finally, there is the constraint $\sum_i p_i(v) \leq 1$. Since we have expressed the problem in terms of $P(v_i)$, the probability that bidder i wins the auction *unconditional* on other bidder's valuations, we have to impose a constraint on $P(v_i)$ so that $P(v_i)$ can be integrated back to a $p_i(v)$ such that $\sum_i p_i(v) \leq 1$. Such constraint has been found by Maskin and Riley (1984). To repeat their condition, here is lemma A.5.

Lemma A.5: *(Maskin and Riley (1984)) Suppose that $P(v_i)$ is piece wise differentiable. The necessary condition for a family of symmetric permutation functions $p_i(v)$ to exist, such that $\sum_i p_i(v) \leq 1$ and $P(v_i) = \int_{v_{-i}} p_i(v) g_i(v_{-i}) dv_{-i}$ is: for any $0 \leq y \leq \bar{v}$,*

$$\int_y^{\overline{v}} P(v_i) f(v_i) dv_i \leq \int_y^{\overline{v}} [F(v_i)]^{n-1} f(v_i) dv_i. \tag{A18}$$

Moreover, if $P(v_i)$ is non-decreasing, (A18) is sufficient for $p_i(v)$ to exist.

We can express this condition by defining a new function $s(y) \geq 0$ such that

$$\int_y^{\overline{v}} P(v_i) f(v_i) dv_i - \int_y^{\overline{v}} [F(v_i)]^{n-1}(v_i) f(v_i) dv_i + s(y) = 0, \tag{A19}$$

Equivalently,

$$s'(y) = \left[P(y) - [F(v_i)]^{n-1}\right] f(y), \tag{A20}$$

since this is true for any y. We will show that $P(v_i)$ is indeed non-decreasing.

Step 8

To summarize, the problem of finding the optimal $\alpha(v_i)$ and $P(v_i)$ becomes

$$\max_{\alpha,P} n \int_{v_i} R(v_i, \alpha(v_i))P(v_i)f(v_i)dv_i \tag{A21}$$

$$s.t. \quad s'(v_i) = \left[P(v_i) - [F(v_i)]^{n-1}\right] f(v_i) \tag{A22}$$

$$\alpha(v_i) = \beta - \frac{c_0}{P(v_i)} \tag{A23}$$

$$s(v_i) \geq 0 \tag{A24}$$

$$\beta - \frac{c_0}{P(v_i)} \geq \underline{\alpha} \tag{A25}$$

This is not a typical optimal control problem, since in addition to the state equation, there are algebraic constraints on both the state variable w and the control variable P. To proceed, we use a mixture of Lagrangian and Pontryagin methods (see Takayama (1985), pp 646-651, for a formal exposition). First, define a generalized Hamiltonian (α is substituted away):

$$H(s, P, \lambda_1, \lambda_2, \lambda_3) = R(v_i)P(v_i)f(v_i) + \lambda_1 \left[P(v_i) - [F(v_i)]^{n-1}\right] f(v_i) + \lambda_2 s + \lambda_3(\beta - \frac{c_0}{P(v_i)} - \underline{\alpha}),$$

where λ_1, λ_2, and λ_3 are the co-state variable, multiplier of constraint $w \geq 0$ and multiplier of constraint $\alpha \geq \underline{\alpha}$, respectively. A set of necessary conditions on the optimal $\alpha(v_i)$ and $P(v_i)$ is the following:

$$\frac{\partial H}{\partial P} = \frac{\partial R}{\partial P}P(v_i)f(v_i) + R(v_i)f(v_i) + \lambda_1 f(v_i) + \lambda_3(-\frac{c_0}{P^2}) = 0; \tag{A26}$$

$$\frac{\partial H}{\partial s} = \lambda_2 = -\lambda_1'; \tag{A27}$$

$$\lambda_2 \geq 0 \quad and \quad \lambda_2 s = 0; \tag{A28}$$

$$\lambda_3 \geq 0 \ \ and \ \ \lambda_3(\beta - \frac{c_0}{P(v_i)} - \underline{\alpha}) = 0. \tag{A29}$$

An analysis of these first order conditions gives the following solution.

Lemma A.6: *Assume that $R(v_i, \alpha)$ is monotonically increasing in v_i for any α constant. If $(\alpha(v_i), P(v_i))$ is the optimal privatization scheme, then for any $v_i \in [0, \bar{v}]$, either $\alpha(v_i) = \underline{\alpha}$ or $P(v_i) = [F(v_i)]^{n-1}$. Furthermore, both cases cannot occur at the same time.*

Finally, from lemma A.4, we know that $P(v_i)[\alpha(v_i) - \beta] = -c_0$ everywhere. Plugging in this condition into equation (A6),

$$U(v_i, x_i) = -c_0(v_i - x_i) - c_0 x_i + U_i(0,0) = -c_0 v_i + U_i(0,0),$$

The expected utility is monotonic decreasing with v_i. We can therefore set $U_i(0,0) = c_0\bar{v}$ so that also the individual rationality constraints are satisfied. Moreover, we can see from such expression that the global incentive constraints are satisfied by our solution, since an individual is never better off by declaring a wrong type, i.e. truth-telling is an equilibrium.

Step 9

Corollary A.1: *Given the $\alpha^*(v_i)$ and $P^*(v_i)$ obtained above, it is never incentive compatible to set reservation prices.*

Proof: Since $\alpha(v_i) < \beta$ always, $R(v_i, \alpha(v_i)) > 0$ always. Therefore, no reservation prices are needed.

Q.E.D.

Step 10

Moreover, if any "bunching" happens, it *only* happens at the lower end of the spectrum of v.

Lemma A.7: *Assume that $R(v_i, \alpha)$ is monotonically increasing in v_i for any α constant. If there exists (a, b), such that $\alpha(v_i) = \underline{\alpha}$ for all $v \in (a, b)$, then there does not exist an interval (c, a) such that $P(v_i) = [F(v_i)]^{n-1}$ for all $v_i \in (c, a)$.*

Proof: The proof is by contradiction.

Step 11

Finally, we can show that some bunching is always optimal. Suppose that there is no bunching at all in $[0, \hat{v}]$, then $P(v_i) = [F(v_i)]^{n-1}$ holds for all v_i. Thus, $P(0) = 0$, which is impossible. As a conclusion, if $v_i \leq \hat{v}$, $P(v_i) = \frac{1}{N}[F(\hat{v})]^{n-1}$ and $c_0 = (\beta - \underline{\alpha})\frac{1}{N}[F(\hat{v})]^{n-1}$

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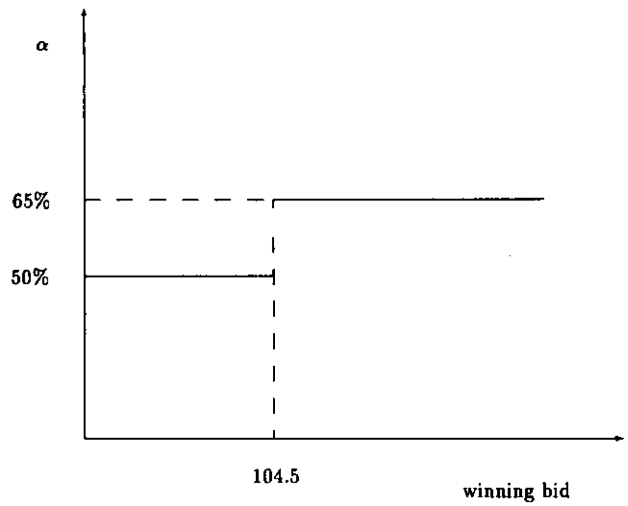

Figure 1:

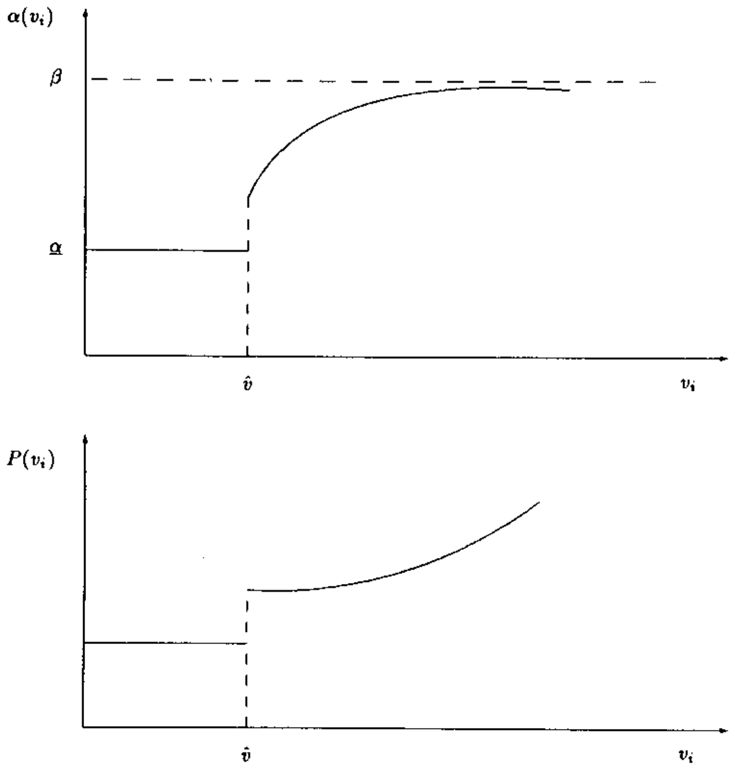

Figure 2:

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