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## Promoting competition in the presence of essential facilities<sup>☆</sup>

Paul A. Grout<sup>a</sup>, In-Uck Park<sup>a,b,\*</sup>

<sup>a</sup>*Department of Economics, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, UK*

<sup>b</sup>*Department of Economics, University of Pittsburgh, 4S01 WW Posvar Hall, Pittsburgh, PA 15260, USA*

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### Abstract

This paper addresses how to use simple access pricing to promote entry in the presence of spillovers and essential facilities. An inherent dilemma is that the greater the spillover, the greater is the benefit of attracting good entrants but the harder it is to exclude low-quality entrants because they can free ride on the quality of good entrants. We show that the inability to discriminate between entrants has the effect of discouraging access prices that enable the low-quality entrant to enter, generates a time consistency problem, and provides incentives for good-quality entrants to limit their competitiveness.

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\* Corresponding author. Department of Economics, University of Pittsburgh, 4S01 WW Posvar Hall, Pittsburgh, PA 15260, USA. Tel.: +1 412 648 1737; fax: +1 412 648 1793.

*E-mail address:* [ipark@pitt.edu](mailto:ipark@pitt.edu) (I.-U. Park).

## 1. Introduction

Optimal pricing for access to essential facilities has received considerable attention in recent years both from economists and policy makers throughout the world. This has focused mostly on network utilities but other issues such as access to ports have received regulatory attention. Recent interest has been driven in part by the wave of privatizations of network utilities around the world and the international drive to open up network markets.<sup>1</sup>

One of the most common access problems arises in networks where a service requires two legs, one a monopoly owned essential facility and the other a potentially competitive segment. Suppliers other than the owner of the essential facility need to interconnect with the monopoly supplier and will generally be expected to contribute to the cost of the essential facility. The appropriate structure of this access charge has been the focus of significant debate within the economics profession. In basic models, a Ramsey pricing rule, or sometimes a very simple version of this often referred to as the Baumol–Willig rule where the access charge is set at the marginal cost of provision plus the opportunity cost, is optimal (see, e.g., Baumol and Sidak (1994) and Laffont and Tirole (1994, 1996)).<sup>2</sup> Where there are issues such as network externalities or unregulated monopoly suppliers, then there will be deviations from these rules (see, e.g., the discussion in Economides (1996)).

A feature of conventional access-pricing rules is that they make entry difficult. The potential entrant has to meet, in the form of an access charge, both the monopolist's marginal cost of the essential facility and the customer's contribution to the monopolist's common cost, and then cover the entrant's own cost before it can profitably enter the market. Once one includes the up-front cost of entry, it is often difficult to compete in the presence of such an access-pricing regime. However, at the same time, it is common for there to be a legal obligation on regulatory agencies to promote effective competition. This is the case in the European Union and within the framework of UK regulatory policy, where regulators have proved resistant to the implementation of conventional access-pricing rules (see, e.g., Grout (1996)). Indeed, the new common framework for regulation in electronic communications in the EU requires regulators to impose regulatory remedies on any company that has significant market power and to have promotion of competition as an explicit objective when deciding on what regulatory intervention and pricing is appropriate.

One of the reasons that regulators tend to favor downstream competition in the presence of essential facilities is that new entrants may bring innovations which spill over and hence improve service to customers and lower the costs of all firms in the market. In this case,

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<sup>1</sup> The wave of privatization that has taken place around the world in the last 20 years has pushed an enormous quantity of assets into the private sector (see, e.g., Dewenter and Malatesta (1997) and Jones et al. (1999)) much of which (e.g., telecommunications, electricity, gas markets) has been accompanied by some form of regulatory control. Even within well-developed economies, regulated privatized companies now account for a significant fraction of the stock market (e.g., at least 13.1% in Germany, 11.7% in Australia, and 7.7% in France (see Megginson and Netter (2001)) with many privatizations still to come. See Grout et al. (2004) for a discussion of the general pricing problems associated with privatization.

<sup>2</sup> The Baumol–Willig rule is based on several specific assumptions, for example, the firms produce perfect substitutes and marginal costs are constant.

positive entry assistance through lower access prices can be beneficial. This, however, raises questions such as how long should the entry assistance last. Furthermore, although a regulatory body may wish to reduce access charges to attract innovatory firms, in many cases, it is difficult for the regulatory body to distinguish, at least in the medium term, between the entrants that will be most beneficial and those that are less beneficial. Indeed, there is an inherent dilemma when pursuing efficiency and wishing to promote competition.

In a dynamic framework with entrants of differing quality technology spillovers have various effects. The positive effect is clear in that good innovations pass to all providers. One negative problem is that spillovers may dilute incentives for an individual company to innovate. This negative effect can arise regardless of the regulator's information.<sup>3</sup> However, if the regulator cannot distinguish good from bad entrants then, in addition to these effects, spillovers offer 'protection' to poor-quality entrants. A low-quality firm can free ride on the quality of a good entrant since it is protected from the consequences of its high costs and poor technology if a good firm has already entered or may be about to enter. The greater the spillover, the greater the desire to attract good entrants but also the harder it is to penalize poor-quality entrants.

We believe that innovations that spill over (in the paper, we assume perfect spillover) are common and a central feature of innovation in the markets we are considering. A good dramatic example of this type arose in the late 1990s in the mobile telecommunications industry. For many years, the standard packages offered to all consumers took the form of a fixed monthly rental paid in advance and an end of month charge for the calls made in the month. This was the standard 'contract' arrangement. Essentially the standard 'landline' model carried over to mobile telephony. As downstream competition intensified in the market, a company decided to offer a 'prepay package' where the consumer purchased the telephone up front in a one-off payment, and from then on, the customer paid in advance for calls and would renew when their limit expired and they had sufficient money to purchase a fresh block of calls. The innovation was expected by the company to be popular with a small group of customers (notably schoolchildren) and to give the company a small competitive edge. In fact, the 'innovation' proved an enormous success, to such an extent that it is now the dominant model in the UK (by far the majority of customers are on prepay packages although high-intensity users still use traditional contract arrangements). Furthermore, the innovation has had a startling social impact. The mobile phone has traditionally been seen as a wealthy consumption good but with the advent of prepay contracts one of the largest groups who have no access to landlines but have mobiles with prepay contracts are single parents on welfare. It is clear why it is ideal product for them. They can cheaply activate a dated secondhand phone and, with a prepay contract, can receive incoming calls and purchase outgoing calls when they have sufficient money. Frequently living in rented accommodation, landlines were not sensible products whereas a mobile moves with them. Along with the immediate consumer welfare gain, there is a wider social benefit of the prepay product through its contribution in reducing the social marginalization that these groups suffer. So in this example, competitive forces

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<sup>3</sup> The regulator's information, however, may influence the extent to which the problem can be offset.

provoked a simple but enormously valuable innovation. However, it was instantly copied by all other retailers, spreading the benefit through the whole market almost overnight. We see this type of innovation, i.e., large innovation with significant spillover, as being quite common and worthy of investigation.<sup>4</sup> Given this focus, the paper complements the existing access-pricing literature in that it deals with issues that have not been addressed to date, in particular, the limitations of simple access pricing in the presence of the spillovers in a game theoretic setting.<sup>5</sup> As far as we are aware, this is the first paper that addresses the spillover issue in the context of access pricing (see [Vogelsang \(2003\)](#) for an excellent summary of the existing access-pricing literature).

The layout of the paper is as follows. Section 2 outlines the model. There is a regulator, an incumbent that owns the essential facility and two potential entrants in the potentially competitive section of the network. The incumbent has a common cost between the two sections of the network. This favors monopoly provision, but the two potential entrants have lower production costs and these spill over when they enter the market. There is a fixed one-off entry cost per firm. The regulator sets a price cap, which has to ensure that the incumbent can finance its activities (i.e., has nonnegative expected profit in equilibrium) and then sets an access-pricing regime which may encourage or discourage entry. There are two time periods, one of the firms arrives in each period, and each has equal probability of being first. We outline and discuss the subgame-perfect equilibria of the model.

Section 3 of the paper considers the position when the regulator can observe whether the first firm is the good one (i.e., lower production cost) or the bad one (i.e., higher production cost). In this case, the regulator is able to implement the first-best solution, and we characterize this. The equilibria “subsidize entry” to accommodate the spillover effect. There are four profiles that are optimal. Either the prices encourage early entry by the good firm but discourage late entry, encourage entry by the good firm at any time, encourage entry by the first firm and discourage entry thereafter, or encourage entry by the good firm at all times and entry by the bad firm in the early period.

As indicated, the process of achieving first-best by subsidizing entry assumes that it is possible to observe whether entrants are good or bad firms. In general, it is more plausible to assume that the regulator is unsure when setting the policy. For example, the UK telecommunications regulatory regime only allowed for one new entrant, Mercury Communications, in the UK market for many years after the privatization of British Telecommunications. One can think of this as a very extreme version of our model. It was far from clear at that time whether Mercury was a good quality competitor. Indeed, *ex post* there are mixed views as to the quality of Mercury as a competitor in this period, and the policy was eventually abandoned in favor of a more open one. Section 4 considers the

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<sup>4</sup> Obviously, the extent of spillover in examples such as this depends critically on the ability or inability to patent ideas.

<sup>5</sup> Indeed, the paper has more in common with the literature on competition policy and innovation than traditional access-pricing models (see, e.g., [Audretsch et al. \(2001\)](#) and [Boone \(2001\)](#)). The closest papers in the access-pricing literature to this paper are [Lewis and Sappington \(1999\)](#) and [De Fraja \(1999\)](#). Both deal with situations where the regulator has less information than the companies, but since they have no overspill, their pricing rules are less conducive to entry than ours and do not address the same issues.

model when it is not possible to identify whether the entrant is the good or bad firm. The question we address is whether the lack of full information encourages the regulator to sustain entry enhancing policies for longer or whether the regulator makes entry harder. We have mentioned above that when it is not possible to observe the types, then the spillover effect makes it harder to use the access-pricing structure to deter poor firms since a regime that wishes to attract a low-cost firm given that a high-cost one has entered cannot prevent a high-cost firm entering in the wake of the low-cost firm since the spillover protects the bad firm from the consequences of its own inefficiency. Similarly, a regime that wishes to attract a higher cost firm in the early stages cannot prevent a low-cost firm earning a positive surplus should it be the first in the market. This prevents the implementation of the first-best. Generally, we show that the incentives are for the regulator to limit entry enhancement rather than be more open in the face of the inability to determine good firms from bad.

Section 4 also addresses certain features of the equilibria. It shows that in the presence of incomplete information, there are profiles which are superior to the implementable profiles but that they are not time consistent. More interestingly, it is shown that for certain configurations, the good firm has an incentive to raise its costs or reduce the cost of its competitor; that is, the good firm wants to become a less good competitor. The intuition for this is that the regulator will not wish to encourage the high-cost firm if its costs are significantly worse than the low-cost firm. In this case, the access-pricing scheme needs to provide no surplus to the good firm. In contrast, if the bad firm is not too inefficient in comparison to the good firm, then the optimal access-pricing scheme ‘prices the high-cost firm into the market’ which implies that the low-cost firm earns a positive expected surplus. That is, the informational rent of the good firm can be increased by reducing the extent of its superiority over the high-cost firm. Section 5 gives conclusions.

## 2. The basic model

The model consists of a regulated market with one incumbent and two potential entrants. The market demand for the final product is represented by a differentiable function  $D(p)$  with derivatives  $D'(p) < 0$  and  $D''(p) > 0$ . The incumbent has control of the upstream part of the network which is an essential facility for access to customers. The current state of technology available to the incumbent for provision of the downstream part of the network is a constant cost per unit. Each potential entrant to the downstream activity has a fixed cost of entry,  $F \in [0, \bar{F}]$ . The two potential entrants differ in the technology they would bring into the industry if they enter. Both costs are below the incumbent’s cost per unit but one of the entrants, referred to as the good type, has the lowest cost technology and the other, referred to as the bad type, has a technology with costs between the incumbent and the good entrant.<sup>6</sup> We use  $g$  and  $b$  as shorthand for the good and bad type

<sup>6</sup> The assumption that the two potential entrants have different types, rather than their types being independent random draws (so that they can both be of the same type), simplifies the results and makes for a particularly clean presentation. This does not affect the main insights (see Section 5).

firms, respectively. For simplicity, we assume without loss of generality that the incumbent's cost per unit is 1, the good entrant's cost per unit is 0, and the bad entrant's cost is  $c$ ,  $0 < c < 1$ . We assume that there is a complete spillover of technology. That is, the lowest cost technology in place in the market at any time can be copied costlessly by others in the industry.<sup>7</sup>

The extensive form game of the model consists of an initiation stage and two subsequent production periods. Formally, we can think of the initiation stage as one where the regulator sets a price cap,  $p$ , which the incumbent either accepts or rejects. If it is rejected, there is no production in the two subsequent periods, and the payoffs to all involved parties are zero. This formalizes the idea that a regulator must allow the regulated firm to fund its activities; that is, the regulated firm will only accept a price cap if the expected profit is nonnegative. If it is accepted, the incumbent is locked in; that is, the incumbent must operate the network in the industry in both periods and provide access to new entrants if they wish. Finally, the regulated firm has a common and fixed cost of  $L > 0$  which is necessary for it to operate in either the upstream or downstream market.

In each of the two periods, a sequence of moves take place: (i) one of the potential entrants arrives at the market, (ii) the regulator sets an access price  $a_i$  for the current period  $i=1, 2$ , (iii) the arrived firm makes an entry decision, (iv) in the absence of price regulation, the market would reach a Cournot solution; given regulation, the firms in the market share the market demand  $D(p)$  evenly at the price cap  $p$  if the Cournot price is above  $p$ ,<sup>8</sup> and (v) each firm in the market pays  $a_i$  to the incumbent. Access prices are allowed to be negative.

One of the two potential entrants (i.e.,  $g$  or  $b$ ) arrives at the market in period 1 (equal probability of each event), and the other arrives in period 2. There are two arrival contingencies that describe candidates' types in the two periods: one arrival contingency is that the first candidate is  $g$  and the second candidate is  $b$ , and the other contingency is the reverse. Candidates are referred to as entrants when they actually enter the market. The type of each candidate is known to firms in the market when it enters but the type may not be known by the regulator. We consider two possibilities for the regulator's information on the candidates' type. As a benchmark, we consider the case where the regulator observes the firm's type on arrival. We then consider the case where the regulator observes the occurrence of entry but not the type of entrants. Access prices can be made contingent upon what the regulator has observed. In the former case, therefore,

<sup>7</sup> The attraction of assuming a complete spillover is that it avoids having to decide on the form of market shares in a situation where there are differing costs and a binding price cap (see Footnote 7). See Section 5 for further discussion of the role played by the *complete* spillover assumption.

<sup>8</sup> Our analysis will focus on environments in which the Cournot prices exceed the optimal price cap. With a binding price cap, the market shares of identically placed firms in a Cournot equilibrium may not be exactly equal since they lie in a range around the equal market shares case. The closer the price cap is to the unconstrained price, the smaller the range. The equal share is the only fixed sharing rule that is compatible with the Cournot assumption for all market sizes where the price cap is binding and makes this the natural case to employ. Note the complete spillover assumption implies all marginal costs are identical.

the regulator has more capacity to control entry by setting access prices contingent upon the arrived candidate's type.<sup>9</sup>

In either case, the regulator sets the price cap and access prices to maximize the expected level of welfare (i.e., the consumers surplus plus the producers surplus) over the two periods. The incumbent and each candidate select their strategies to maximize (expected) surplus over the two periods, which is total revenue in excess of total expense. There is no discounting. The description of the game is common knowledge, and we focus on the subgame-perfect equilibria of this game.

Abusing notation slightly, it is convenient to use  $g$  and  $b$  to represent the entry of good and bad types, and we use  $\emptyset$  to represent no entry. An *entry sequence* is an ordered pair  $r \in \{\{g, \emptyset\} \times \{b, \emptyset\}\} \cup \{\{b, \emptyset\} \times \{g, \emptyset\}\}$  that represents a sequence of entry decisions by the two potential entrants in periods 1 and 2. An *entry profile* is an ordered pair of entry sequences  $A = \langle r, r' \rangle$  where  $r$  is the entry sequence given that  $g$  arrives first, and  $r'$  is the entry sequence given that  $b$  arrives first. For example, an entry profile  $\langle (g, b), (b, \emptyset) \rangle$  describes the following: If  $g$  arrives first both candidates enter in due course, while in the alternative case (i.e., if  $b$  arrives first)  $b$  enters in period 1 but  $g$  does not enter in period 2. There are four possible entry sequences for each arrival contingency, so there are 16 entry profiles. The regulator's objective is to implement the best possible entry profile in the most efficient way, by setting the price cap and access prices to provide the right incentives for the producers.

An access-pricing strategy is a strategy of the regulator which consists of a price cap  $p$  and access prices contingent on the history observable by the regulator. Given an access-pricing strategy, we apply a backward induction argument to determine each potential candidate's entry decision for each possible history. Recording the entry decisions that would be realized for each arrival contingency, we derive an entry profile that is a 'best-response' to the given access-pricing strategy. Every entrant in this profile derives nonnegative expected surplus. Note, however, that whether a best response profile can be implemented or not further depends on the incumbent's incentives: even if a profile is the best-response to an access-pricing strategy, the regulator cannot induce it using the associated access-pricing strategy in equilibrium if the incumbent expects a negative surplus from it, because then the incumbent would block it by rejecting the price cap that the regulator would set. To reflect the incentives of all producers, we say that a profile is *incentive compatible* at a price cap  $p$  if (i) it is a best-response to an access-pricing strategy whose price cap component is  $p$  and (ii) the incumbent derives nonnegative expected surplus. Next, we consider the regulator's incentives.

The surplus of each producer is defined in the natural way. That is, the surplus of each entrant is the total revenue in excess of total cost including the entry cost  $F$  and the access price transfers. The (expected) surplus of the incumbent is total revenue (revenues and

<sup>9</sup> The assumption that the firms know the quality of the entrant while the regulator only observes entry but not quality is the core difference between the latter case and the former. We believe that asymmetry of information between firms in an industry and the regulatory agency overseeing that industry is sufficiently realistic and common to warrant exploration. Note that no firm has a strict incentive to reveal the quality of the entrant to the regulator even if some firms had this ability. The assumption that the regulator knows the distribution of types but not the quality of any particular player is relatively standard. Note, we assume that the regulator knows the exact value of  $c$  even when he/she does not observe the type of the entrant. The main results, however, go through when the perceived cost levels include small noise (using the same intuition for the robustness of our results as explained in Section 5).

access price receipts) minus costs including the common cost  $L$ . The producers' surplus is the sum of surpluses of all producers, and total welfare is consumers' surplus plus producers' surplus. Once a price cap,  $p$ , is accepted, a subgame starts in which the incumbent is locked in, so that the regulator may induce any profile as long as it is a best-response (in terms of entry decisions) to some access prices given the price cap  $p$ . In that subgame, therefore, the regulator would implement a profile that generates the highest welfare among all such profiles. This profile is called *subgame-optimal* at  $p$ . Given a price cap, the welfare level generated by a profile is not affected by the access prices used to induce it, because they are only transfers between producers.

Combining the incentives of the producers and the regulator, we say that an entry profile is *implementable* at  $p$  if it is incentive compatible and subgame-optimal at  $p$ . The optimal profile that the regulator will indeed implement is the one that generates the highest welfare among all profiles that are implementable (at some  $p$ ). For small market demand, the Cournot price may fall short of the optimal price cap the regulator will set. When the market demand is sufficiently large, however, the Cournot price is so high that the price cap that the regulator sets to maximize the total welfare becomes binding. In this paper, our analysis focuses on the latter type of environment by assuming that the minimum price cap at which a profile is implementable is binding in all supply conditions.<sup>10</sup> It facilitates the analysis and allows us to get results for a general class of demand functions (i.e., without specifying a function form). However, the main insights of the paper are robust to this presumption as explained in Section 5.

### 3. Complete information and the first-best

The key instruments that the regulator uses to induce the optimal entry profile are the access prices that transfer payoffs between the producers. In the benchmark case that the regulator observes the type of candidates, he/she can induce any transfers between producers by using appropriate access prices, as long as every producer has nonnegative surplus. In particular, transfers can be made in such a way that every entrant has zero surplus, and the incumbent reaps the entire producers surplus. Therefore, an entry profile is incentive compatible at a price cap  $p$  if and only if the producers' surplus is nonnegative at  $p$ . If the regulator can commit to an access-pricing strategy (i.e., subgame optimality is irrelevant), he/she will compare the welfare levels from all profiles at the price caps at which they are incentive compatible and implement the one that generates the highest welfare. We refer to this profile as *first-best* (implicitly in association with the price cap that generates the highest welfare).

Note that we have not considered subgame optimality in defining the first-best. When commitment is not possible as is the case in our model, therefore, the first-best is not necessarily implementable because it may not be subgame-optimal at the associated price

<sup>10</sup> The supply condition with the lowest Cournot price is when both firms entered. The minimum price caps at which various profiles are implementable are characterized later by Eqs. (3) (4) (5). Hence, this assumption says that these minimum price caps are lower than the Cournot price of the case that all three firms operate at production cost of 0 (due to spillover). Since  $F$  is bounded, given any decreasing function  $D^0(p):\mathbb{R}_+\rightarrow\mathbb{R}_+$ , this condition is satisfied for all demand functions  $D(p)=a+D^0(p)$  if  $a>\underline{q}$  for some  $\underline{q}>0$ .

cap. We show later that this problem does not arise in the benchmark case: the first-best is in fact subgame-optimal, and therefore, the regulator will implement it. First, we identify the first-best.

The relative performance of entry profiles (hence, the first-best) varies depending on the parameter values of  $c$  and  $F$ . Given a “cost configuration”  $(c, F) \in (0, 1) \times \mathbb{R}_+$ , we say that an entry profile  $A$  dominates another profile  $A'$  at  $p$ , if the welfare from  $A$  exceeds the welfare from  $A'$  at the price cap  $p$ . The next results identify several entry profiles that are always dominated when the price cap is binding.

**Lemma 1.** *Given any cost configuration  $(c, F)$  and a binding price cap  $p$ ,*

- (i)  $\langle (g, \emptyset), r^h \rangle$  dominates  $\langle (g, b), r^h \rangle$  at  $p$ ;
- (ii)  $\langle (g, \emptyset), r^h \rangle$  dominates  $\langle (\emptyset, b), r^h \rangle$  at  $p$ ;
- (iii)  $\langle (g, \emptyset), (\emptyset, \emptyset) \rangle$  dominates  $\langle (\emptyset, \emptyset), r^h \rangle$  at  $p$  if  $r^h \neq (\emptyset, \emptyset)$ .

**Proof.** Obviously  $(g, \emptyset)$  generates a larger producers surplus than  $(g, b)$  because the second period entry  $b$  incurs the entry cost  $F$  without lowering cost of production. Since the consumers surplus depends only on the price cap (not the profile), part (i) follows. Analogous arguments establish parts (ii) and (iii).  $\square$

An entry profile is not first-best for any  $(c, F)$  if it is always dominated by another profile. By Lemma 1, the profiles that may survive this dominance test are the four profiles of the form  $\langle (g, \emptyset), r^h \rangle$  and the null profile  $\langle (\emptyset, \emptyset), (\emptyset, \emptyset) \rangle$ . We denote these as:

$$A^0 = \langle (\emptyset, \emptyset), (\emptyset, \emptyset) \rangle$$

$$A^1 = \langle (g, \emptyset), (\emptyset, \emptyset) \rangle$$

$$A^2 = \langle (g, \emptyset), (\emptyset, g) \rangle$$

$$A^3 = \langle (g, \emptyset), (b, \emptyset) \rangle$$

$$A^4 = \langle (g, \emptyset), (b, g) \rangle.$$

To determine the first-best, therefore, we need only consider these five profiles. Let  $\bar{c}_i$  and  $\bar{e}_i$  be, respectively, the mean production cost per unit and the expected number of entry for profile  $A^i$ . For example,  $\bar{c}_1 = \bar{e}_1 = 1/2$  and  $\bar{c}_4 = c/4$  and  $\bar{e}_4 = 1.5$ . Then, the expected level of total welfare  $W_i(p)$  from  $A^i$  at a price cap  $p$  (which is binding) is:

$$W_i(p) \equiv 2 \int_p^\infty D(\rho) d\rho + 2pD(p) - 2\bar{c}_i D(p) - \bar{e}_i F - L \tag{1}$$

where the first term is the consumers surplus over the two periods, and the remainder characterizes the producers surplus. The latter is the total industry revenue over the two periods,  $2pD(p)$ , minus the total expected industry expense that consists of expected industry production cost  $2\bar{c}_i D(p)$ , expected entry cost  $\bar{e}_i F$ , and the network operation cost  $L$ .

From the first derivative, i.e.,  $W_i'(p) = 2(p - \bar{c}_i)D'(p)$ , it follows that  $W_i(p)$  monotonically decreases in  $p$  for  $p > \bar{c}_i$ . Since incentive compatibility implies  $p > \bar{c}_i$  (otherwise the industry revenue does not cover total production cost, let alone the operation cost  $L$  and the entry cost), the price cap that maximizes welfare subject to inducing  $A^i$  is the lowest price that satisfies the incentive compatibility constraint.

Recall that in the complete information regime access prices can be selected in such a way that every entrant has zero surplus and the incumbent reaps the entire producers' surplus. Therefore, an entry profile  $A^i$  is incentive compatible at a price cap  $p$  if and only if the expected level of producers surplus is nonnegative at  $p$ :

$$2(p - \bar{c}_i)D(p) \geq \bar{e}_i F + L, \quad (2)$$

that is, the expected aggregate sales profit exceeds the common cost plus the total expected entry costs. Let  $p^i(c, F)$  denote the smallest  $p$  that satisfies Eq. (2) for each  $(c, F)$ , if exists.<sup>11</sup> For future reference, we write out the relation (2) for each  $A^i$ : the function  $p^i$  (if defined) is the smallest solution to

$$\begin{aligned} A^0: & (2p^0 - 2)D(p^0) = L \\ A^1: & (2p^1 - 1)D(p^1) = F/2 + L \\ A^2: & (2p^2 - 1/2)D(p^2) = F + L \\ A^3: & (2p^3 - c)D(p^3) = F + L \\ A^4: & (2p^4 - c/2)D(p^4) = 3F/2 + L. \end{aligned} \quad (3)$$

Together with the earlier finding that  $W_i(p)$  decreases in  $p$  as long as incentive compatibility is satisfied, we deduce that the maximum welfare of  $A^i$  subject to incentive compatibility is obtained with a price cap  $p^i(c, F)$ . Since the producers surplus is zero at this price cap, the maximum total welfare from  $A^i$  is the consumers' surplus at the price cap  $p^i(c, F)$ . Because a lower price cap means larger consumers' surplus, we have

**Lemma 2.**  $A^i$  is a first-best profile at  $(c, F)$  if and only if  $p^i(c, F)$  exists and  $p^i(c, F) \leq p^j(c, F)$  whenever  $p^j(c, F)$  exists.

As such, the first-best profile is determined by comparing the levels of  $p^i(c, F)$ . However, this comparison encounters inessential, technical complication if the functions  $p^i$  are discontinuous in  $F$ , which is the case if any of the left hand side (LHS) of Eq. (3) attains multiple local maxima as a function of  $p$ . We circumvent this complication by focusing on demand functions  $D$  such that the LHS of the equations in Eq. (3) are quasiconcave<sup>12</sup> as functions of  $p$ :

[A1]. For all  $\bar{c} \in (0, 1)$ ,  $2(p - \bar{c})D(p)$  is quasiconcave for  $p > \bar{c}$ .

Then, the LHS of Eq. (3) is either single-peaked or monotonically increasing<sup>13</sup> and, therefore, a solution to each equation at which the LHS is increasing constitutes the

<sup>11</sup> To be precise,  $p^i(c, F)$  also depends on  $L$  but we omit this dependence because  $L$  is treated fixed. Note also that the argument  $F$  is redundant for  $p^0(c, F)$ .

<sup>12</sup> A function  $f$  is quasiconcave if the upper contour set  $\{x: f(x) \geq r\}$  is convex for every  $r \in \mathbb{R}$ .

<sup>13</sup> [A1] implies that  $2(p - \bar{c})D(p)$  strictly increases until it reaches the maximum, then strictly decreases. See Lemma A6 in the Appendix.

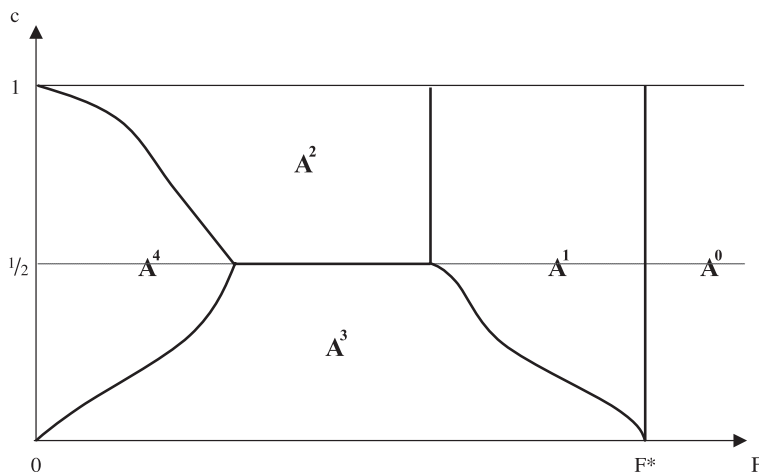


Fig. 1. First-best entry profile.

optimal price cap. This condition is satisfied by various (demand) functions such as  $D(p)=a+b/p$  for  $a,b>0$  and  $D(p)=a+e^{-bp}$  for  $a \geq e^{-2}$  and  $b>0$ .<sup>14</sup> Furthermore, we note here that the main results of this paper hold for a large class of demand functions that do not meet this condition. Finally,  $L$  is assumed to be small enough so that

**[A2].** The first equation of Eq. (3) has a solution  $p^0=p^0(c,F)$  for all  $(c,F)$ .

This ensures that at least one profile satisfies incentive compatibility for all  $(c,F)$ , hence first-best exists.

Fig. 1 illustrates typical regions of cost configurations  $(c,F)$  for which the five profiles  $A^0$ – $A^4$  are first-best. The intuition for the partition in Fig. 1 is clear. If entry incurs a very large fixed cost ( $F>F^*=2D(p^0)$ ), then no entry is justified, so the null profile,  $A^0$ , is first-best for all  $c$ . For lower values of  $F$  some entry is induced, and the good firm is always made to enter if it arrives first. Clearly, if the regulator does not wish the good firm to enter if it arrives first, then the regulator must not want any entry (as indeed is the case when  $F>F^*$ ). When  $F(<F^*)$  is relatively high and there is a significant difference in quality between the good and bad firm, the optimal strategy is to allow nothing other than entry by the good firm in the first period. If the good firm does not arrive until later, then the costs of entry make it inefficient for it to enter since there is only one period of benefit from the entry of the good firm. As  $F$  falls, it becomes sensible to allow more entry. If the production cost of the bad firm,  $c$ , is close to the good firm, then the optimal strategy is to make the first firm enter whether good or bad. If the production cost of the bad firm is closer to the incumbent than the good firm, on the other hand, the optimal strategy is to make the good firm enter whether it arrives first or second and to prevent the bad firm in all situations. Finally, if  $F$  is sufficiently low, then it becomes sensible to force entry of

<sup>14</sup> For  $D(p)=a+b/p$  it is easy to verify that the first derivative of  $2(p-\bar{c})D(p)$  is positive for  $p>0$ . For  $D(p)=a+e^{-bp}$ , the first derivative of  $2(p-\bar{c})D(p)$  decreases then increases and assumes a nonnegative value at the inflexion point if  $a \geq e^{-2}$ .

either firm in the first period and to force entry of the good firm if it arrives later. This typical partition of first-best regions is generalized as follows.

**Proposition 1:** *There are continuous functions  $f_4, f_3, f_2, f_1: (0,1) \rightarrow \mathbb{R}_+$  that characterize first-best profiles as below.*

- (a) Given  $c \in (1/2, 1)$ :  $0 < f_4(c) \leq f_2(c) \leq f_1(c)$  and  $A^4$  is the unique first-best for  $F \in (0, f_4(c))$ ,  $A^2$  is the unique first-best for  $F \in (f_4(c), f_2(c))$ ,  $A^1$  is the unique first-best for  $F \in (f_2(c), f_1(c))$ , and  $A^0$  is the unique first-best for  $F \in (f_1(c), \bar{F})$ .
- (b) Given  $c \in (0, 1/2)$ :  $0 < f_4(c) \leq f_3(c) \leq f_1(c)$  and  $A^4$  is the unique first-best for  $F \in (0, f_4(c))$ ,  $A^3$  is the unique first-best for  $F \in (f_4(c), f_3(c))$ ,  $A^1$  is the unique first-best for  $F \in (f_3(c), f_1(c))$ , and  $A^0$  is the unique first-best for  $F \in (f_1(c), \bar{F})$ .
- (c) For  $c = 1/2$ :  $0 < f_4(c) \leq f_3(c) = f_2(c) \leq f_1(c)$  and  $A^4$  is the unique first-best for  $F \in (0, f_4(c))$ , only  $A^2$  and  $A^3$  are first-best for  $F \in (f_4(c), f_2(c))$ ,  $A^1$  is the unique first-best for  $F \in (f_2(c), f_1(c))$ , and  $A^0$  is the unique first-best for  $F \in (f_1(c), \bar{F})$ .

**Proof.** See Appendix.  $\square$

The main purpose of this section is to describe the optimal profiles to implement when the regulator has complete information. He/she would implement the first-best if it is subgame-optimal, but this is not guaranteed: once the incumbent accepts the optimal price cap for the first-best profile, he/she is locked in, and the regulator may induce another profile that generates higher welfare even if it incurs a loss to the incumbent. In this case, the incumbent would anticipate this and reject the price cap and the first-best profile would not be implementable. It turns out that this problem does not arise in the complete information regime: since any profile can be induced in such a way that the incumbent reaps the whole producers surplus, a profile that dominates the first-best in the subgame would have been incentive compatible at the same price from the start and, hence, would have been preferred by the regulator. Therefore, the first-best will indeed be implemented by the regulator.

**Theorem 1.** *If the regulator observes the types of entrants, then for each  $(c, F)$  he/she will implement a first-best profile at the minimum price cap subject to the incentive compatibility constraint (i.e., Eq. (2)).*

**Proof.** Consider an arbitrary  $(c, F)$  and a first-best profile  $A^i$  at  $(c, F)$ . If the regulator sets price cap  $p^i(c, F)$  and the incumbent accepts it, the regulator can set access prices (contingent on the entrants) to induce  $A^i$ : In this case, every entrant has a net surplus of 0 and the incumbent, reaping the entire producers' surplus, also gets a net surplus of 0. If the regulator sets a price cap  $p < p^i(c, F)$ , then the incumbent would not accept it because the total producers' surplus would be negative regardless of the entry profile that may be induced because  $p^i(c, F) \leq p^j(c, F)$  for all  $j \neq i$ . In addition, for each  $j$ , setting  $p > p^j(c, F)$  and inducing  $A^j$  reduces total welfare because  $W_j'(p) < 0$  for  $p \geq p^j(c, F)$  as shown earlier. Hence, it suffices to show that once the incumbent accepts  $p^i(c, F)$ , the regulator has no incentive to deviate from inducing  $A^i$ . Since the total consumers' surplus is fixed once  $p^i(c, F)$  is accepted (recall that  $p^i(c, F)$  is binding), the regulator would have an incentive to deviate only if he/she can increase the total producers' surplus by inducing some other

profile, say  $A^j$ . This would mean that he/she could set the price cap slightly lower than  $p^i(c, F)$  and still induce  $A^j$  without violating incentive compatibility, contradicting our presumption that  $A^i$  is first-best, i.e.,  $p^i(c, F) \leq p^j(c, F)$  for all  $j \neq i$ .  $\square$

#### 4. Incomplete information

We now consider the case where the regulator is unable to identify which firm has arrived in each period and so the access prices cannot depend on the entrant's type. However, the regulator observes entry and, therefore, the second period's access price can depend on whether an entry occurred in the first period or not. If the regulator could still implement the first-best profiles at the same price cap levels that are described in the previous section, then the optimal access pricing and its welfare implication would remain the same. Although there are some profiles that can be implemented in this manner, the inability to observe the types of entrants generally restricts the regulator's capacity to control entry using access pricing. As we will show, some entry profiles are now either implemented less efficiently because producers surplus cannot be extracted fully, or not implementable at all because the right incentives cannot be provided.

The complication for the regulator arises because either type of the first-arrived firm, once it has entered, must face the same revenues and access prices. This has two consequences:

- (a) One is that if the regulator wishes to accommodate  $b$  in the first period (and sets access prices accordingly), then  $g$  must also be accommodated at the same price if it arrives first although  $g$  would enter even if the access price was set a bit higher. In these cases, the  $g$  entrant necessarily enjoys a positive profit, i.e., an "informational rent" due to incomplete information. This implies that such profiles cannot display zero expected surplus for  $g$ . That is, profiles such as  $A^3$  are now more expensive to implement.
- (b) Given that the first candidate is accommodated regardless of type, then if the regulator wishes to encourage  $g$  to enter in the second period, he/she cannot stop  $b$  from also entering in the second period. This follows from the complete spillover assumption: although  $b$ 's entry does nothing to reduce production costs,  $b$ 's production costs on entry will immediately fall to zero since  $g$  is already in the market and, therefore,  $b$  has the same incentive to enter as  $g$  in the second period. This means that the profile  $A^4$  is no longer implementable. Either  $A^4$  must be replaced with other undominated profiles (such as  $A^2$  or  $A^3$ ) or an alternative profile

$$A^5 = \langle (g, b), (b, g) \rangle$$

which recognizes that  $r^b(b, g)$  implies  $r^g(g, b)$ . It is straightforward to verify that among the profiles that are always dominated under complete information as per Lemma 1,  $A^5$  is the only one that ceases to be so under incomplete information (because  $A^4$  is no longer implementable and hence, is eliminated from consideration).

It is obvious that the null profile  $A^0$  can be implemented in the first-best way without observing the firms' type, by setting a price cap  $p^0(c, F)$  and prohibitively large access

prices. The same is true for the profiles  $A^1$  and  $A^2$ : since entry by  $b$  is blocked, the desired entries can be implemented via self-selection without incurring informational rent. So, the welfare level in the first-best regions for these three profiles is unaffected by the inability to observe the entrant’s type. Formalizing this intuition, we have

**Lemma 3.** *Under incomplete information, it is optimal for the regulator to implement  $A^0$ ,  $A^1$ , and  $A^2$  in the first-best way in the regions for which they are first-best.*

**Proof.** By Theorem 1,  $A^i$  is implementable at  $p^i(c, F)$  under complete information if  $A^i$  is first-best for  $(c, F)$ . First, we show for  $i=2$  that the same is true under incomplete information. Consider the access prices used to implement  $A^2$  under complete information: let  $a_1(t)$  be the access price when the first-arrived candidate is  $t=g, b$ , let  $a_2(b)$  be the access price in the second period when  $b$  arrived in period 1 but did not enter, and let  $a_2(g)$  be the access price in the second period when entered in period 1. Under incomplete information, consider the price cap  $p^2(c, F)$ , and access prices  $a_1(g)$  in the first period,  $a_2(b)$  in the second period without previous entry, and  $a_2(g)$  in second period with previous entry. Then, the first-arrived  $g$  candidate, if it enters, induces the same entry profile at the same access prices as under complete information, hence would enter and earn zero net surplus: implicit in this argument is that the second candidate,  $b$ , facing the same situation as in the complete information regime, would not enter given that  $g$  entered previously. It is straightforward to verify that if the  $b$  candidate arrives first and enters, this firm does worse than a  $g$  firm who arrives first and enters, since the good firm earns zero surplus as explained above. Hence, the candidate does not enter if it arrives first. Given this, the  $g$  candidate enters in the second period as it does in the complete information regime. This establishes that  $A^2$  is subgame-optimal at  $p^2(c, F)$ . Since incentive compatibility is the same under complete and incomplete information regimes,  $A_2$  is implementable at  $p^2(c, F)$  under incomplete information as well. Being

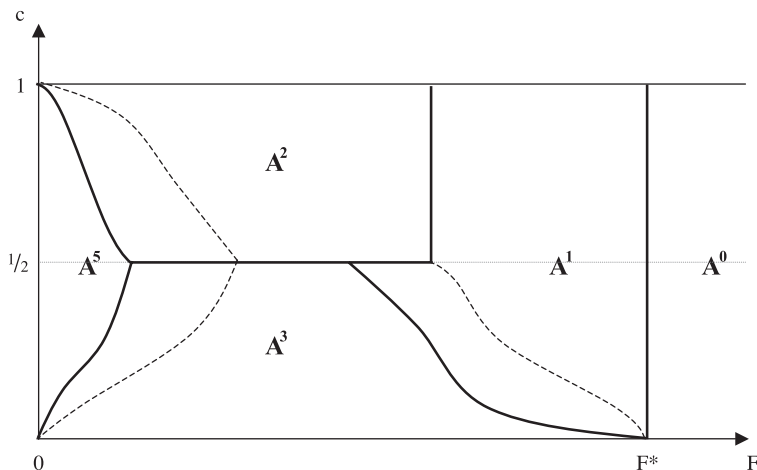


Fig. 2. Optimal profile under incomplete information.

first-best at  $(c,F)$ , this is clearly optimal under incomplete information. Analogous (and simpler) arguments establish the same conclusion for  $A^1$  and  $A^0$ .  $\square$

The first-best cannot be achieved for configurations  $(c,F)$  for which  $A^3$  or  $A^4$  is the unique first-best. For such  $(c,F)$ , the optimal profile to implement is the one that generates the highest welfare subject to incentive compatibility and subgame optimality under incomplete information. Fig. 2 illustrates a typical pattern of the optimal entry profiles under incomplete information. The broken lines indicate the regions from Fig. 1. Although our formal result will be more general, we first provide an informal explanation of the optimal profiles under incomplete information as illustrated in Fig. 2. In the light of Lemma 3, to justify Fig. 2, we need to examine the optimal profiles for configurations  $(c,F)$  for which  $A^3$  or  $A^4$  is the only first-best, referred to as the “inefficient area.” To start with, we clarify how  $A^3$  and  $A^5$  may be implemented under incomplete information.

For  $A^3 = ((g, \emptyset), (b, \emptyset))$ , the maximum possible transfer from each entrant to the incumbent (as access price payments over the two periods) is  $(p - c)D(p) - F$ , the revenue of  $b$  in excess of  $F$ , where  $p$  is the effective price cap. Then, the incumbent’s incentive constraint is

$$(p - \bar{c}_3)D(p) + (p - c)D(p) - F \geq L \Leftrightarrow \left(2p - \frac{3}{2}c\right)D(p) \geq F + L \tag{4}$$

which obviously implies that the price cap must be higher than  $3c/4$ . Recall from Eq. (1) that  $W_3(p)$  decreases monotonically for  $p > c/2 (= \bar{c}_3)$ . So, the optimal price cap that maximizes  $W_3$  subject to Eq. (4) is the lowest one that satisfies Eq. (4), which we denote by  $p_*^3(c, F)$ . Note  $p_*^3(c, F) > p^3(c, F)$ .

For  $A^5 = ((g, b), (b, g))$ , the maximum possible transfer from the second period entrant in either contingency is  $pD(p)/3 - F$ . The maximum possible transfer from the first period entrant in either contingency is  $(p - c)D(p)/2 + pD(p)/3 - F$ , and  $g$  earns a positive rent if enters in the first period. So, the incumbent’s incentive constraint is:

$$\begin{aligned} & \frac{1}{2} \left( \frac{5}{6}pD(p) + \frac{1}{2}(p - c)D(p) + \frac{1}{3}pD(p) \right) + \frac{(p - c)D(p)}{2} + \frac{2pD(p)}{3} \\ & - 2F \geq L \Leftrightarrow \left(2p - \frac{3}{4}c\right)D(p) \geq 2F + L. \end{aligned} \tag{5}$$

The optimal price cap that maximizes  $W_5$  subject to Eq. (5) is the lowest one that satisfies Eq. (5), which we denote by  $p_*^5(c, F)$ .

In the inefficient area for  $c \in [1/2, 1)$ , we need to consider profiles  $A^0, A^1, A^2$  and  $A^5$  to determine the optimal one ( $A^3$  is dominated by  $A^2$ ). Note, however, that we only need to compare  $A^5$  with  $A^2$  because  $A^2$  dominates  $A^0$  and  $A^1$  for  $F \leq f_4(c)$ . Since  $A^2$  and  $A^4$  are equivalent at  $f_4(c)$  and  $A^5$  performs worse than  $A^4$ , we deduce that implementing  $A^2$  at the optimal price cap  $p^2(c, f_4(c))$  (which is possible by Lemma 3) is strictly better than  $A^5$ . As  $F$  falls from  $f_4(c)$ , it hits a level, say  $F(c)$ , at which inducing  $A^2$  ceases to be subgame-optimal once  $p^2(c, F)$  has been accepted by the incumbent, because  $F$  is so low that inducing more entry, i.e.,  $A^5$ , enhances total welfare although it would inflict a loss for the

incumbent due to additional entry that increases competition. Anticipating this, the incumbent would not accept the price cap  $p^2(c, F)$  if  $F < F'(c)$  and, therefore, the regulator has to offer a higher price cap to induce  $A^2$ . Although the performance of inducing  $A^2$  is restricted by this constraint, it is still better than inducing  $A^5$  for  $F < F'(c)$  sufficiently close to  $F'(c)$ , because inducing  $A^5$  incurs inefficiency associated with providing an informational rent for the  $g$  entrant. As  $F$  falls even further, it hits a level, say  $f_5^*(c) < F'(c)$ , at which the savings in production cost due to additional entry overcompensates the (ever decreasing) extra entry cost, so that  $A^5$  can be induced with a lower price cap than  $A^2$  to such an extent that inducing  $A^5$  becomes optimal.

In the inefficient area for  $c \in (0, 1/2)$ , we need to compare  $A^5$ ,  $A^3$  and  $A^1$  to determine the optimal profile because  $A^3$  has deteriorated relative to the complete information regime. It is clear that the boundary of the region for which  $A^3$  is optimal retreated against the region for which  $A^1$  is optimal, that is,  $f_3^*(c) < f_3(c)$ , where  $f_3^*(c)$  is the supremum of  $F$  for which  $A^3$  is optimal under incomplete information. As  $F$  falls further from  $f_3^*(c)$ , the optimal profile switches from  $A^3$  to  $A^5$  at some level, say  $f_5^*(c)$ , by the same reasoning as explained above for  $c \geq 1/2$ . It turns out that  $A^2$  and  $A^3$  are equivalent when  $c = 1/2$  and  $F = f_5^*(1/2)$ : as  $F$  falls from  $f_4(1/2)$ , subgame optimality constraint requires a price cap higher than  $p^2(1/2, F)$  for  $A^2$ , which entirely removes the advantage of  $A^2$  over  $A^3$  under incomplete information at  $F = f_5^*(1/2)$ . Up to now, we explained the optimal profiles in the inefficient area of Fig. 1 under incomplete information. The next theorem provides a more general characterization of optimal profiles in the inefficient area.

**Theorem 2.** (a) *The region of cost configurations  $(c, F)$  for which  $A^5$  is optimal under incomplete information is a proper subset of the region for which  $A^4$  is first-best.* (b) *The region of  $(c, F)$  for which  $A^5$  or  $A^3$  is optimal under incomplete information is a proper subset of the region for which  $A^4$  or  $A^3$  is first-best.*

**Proof.** See Appendix.  $\square$

It follows from Theorem 2 and the preceding discussion that the set of cost configurations where prices are chosen such that there is potential for second period entry with incomplete information is a subset of the equivalent when there is full information. Also in the absence of full information, the set of cost configurations where bad and good firms may simultaneously coexist in the market and the set of cost configurations where the bad firm is ‘priced into the market’ are both proper subsets of the equivalent with full information. These are the senses in which we suggest that the inability to distinguish good from bad firms will encourage the regulator to stop promoting entry sooner and in general will be less supportive of potential entry.

It is clear that once the regulator has incomplete information, then the incentives become complex. Here we present two insights that follow from our analysis. One is that better profiles exist but they are not time consistent.<sup>15</sup> Second, that the good firm can benefit from being a less good competitor. We cover these in turn.

<sup>15</sup> The effect here is akin to the conventional incomplete contracts problem, e.g., Grout (1984), Hart (1995) and Hart and Holmstrom (1987).

**Proposition 2.** *For some configurations  $(c, F)$ , there exists an entry profile that is incentive compatible at some price cap and exhibits higher welfare than the equilibrium profile, but is not time consistent, i.e., not subgame-optimal.*

A formal proof of the proposition is given in the Appendix. The intuition for this result is as follows. As first-best profiles  $A^2$  and  $A^3$  are equivalent at the boundary between the corresponding regions. With incomplete information, the welfare value of  $A^2$  is unaffected because, as verified earlier, entry of  $b$  is blocked and no information rent needs to be incurred. To induce  $A^3$ , however, a positive rent is necessary for  $g$  in order to accommodate  $b$  in the first period, so the welfare of  $A^3$  is lower compared to the complete information regime. It follows that there must be a discrete drop in welfare at the boundary between the optimal regions for  $A^2$  and  $A^3$  when there is incomplete information. For values of  $c$  lower than but “close” to  $1/2$ , profile  $A^2$  is incentive compatible given the price cap and access prices that are optimal when  $c=1/2$  (because the profit from entry would be the same at 0 for the  $g$  firm and slightly higher for the  $b$  firm but still negative), hence would exhibit a higher level of welfare than profile  $A^3$ . However,  $A^2$  cannot be implemented for such values of  $c$  because it is not subgame-optimal. That is, whatever the level of the price cap, once it is set, the regulator finds  $A^3$  a better profile to induce than  $A^2$ , because  $c$  is sufficiently low that the benefit from entry of  $b$  for two periods surpasses the benefit from entry of  $g$  for one period. Implementing  $A^3$  rather than  $A^2$  at this price cap would generate an insufficient return to the incumbent. Foreseeing this, the incumbent will only accept price caps that are sufficiently high to generate enough return to the incumbent when  $A^3$  is induced.

The time inconsistency in Proposition 2 concerns the number of firms that the regulator wants in the market. If the regulator could precommit to a regulatory entry policy, there are cases where he/she would wish to take an aggressive antientry policy (i.e., price the bad firm out of the market). However, when the regulator gets to this point (because the price cap has been fixed), he/she will then decide to take a liberal attitude to entry and adopt lower access prices to promote early entry.

**Proposition 3.** *For some configurations  $(c, F)$ , the good firm can gain when its superiority over the bad firm is smaller, i.e., if it becomes a less good competitor.*

The intuition for this result follows from Proposition 2 and is obvious, as explained below, so a formal proof is not needed. Note that the value of  $c$  represents the relative position of the production cost of the bad firm to those of the good firm and the incumbent, so smaller superiority of the good firm means lower  $c$ . The good firm earns an information rent in  $A^3$  that it does not earn in  $A^2$ . Therefore, it experiences a discrete jump in profit from 0 as the equilibrium profile shifts over from  $A^2$  to  $A^3$ , which takes place if  $c$  falls below a certain threshold for some values of  $F$ . Analogous logic is in force at the boundary between  $A^2$  and  $A^5$  and between  $A^1$  and  $A^3$ .

Slightly stepping outside of the current model, the good firm may privately reduce (but not increase) its superiority at the beginning of the game. Then, there exist multiple equilibria depending on the belief of the regulator. In particular, there exist equilibria in which the regulator believes that the good firm reduces its superiority to a certain level

to increase its profit, hence sets the price cap and access prices optimally for the reduced level because any lower price cap would not be accepted by the incumbent who shares the equilibrium belief.<sup>16</sup> Although the details depend on the specifics of the extended model, one could imagine that an improvement in the bad firm relative to the good could perhaps happen by the good firm leaking some of its know-how to the bad firm. If the good firm cannot influence the bad firm's cost, it could weaken its comparative position by raising its own production cost. The main point is that the good firm has apparently perverse incentives when the regulator has incomplete information.

## 5. Conclusions

The paper has considered the problems that arise when there are sound economic arguments for promoting competition in the presence of essential facilities but the regulatory agencies cannot distinguish between entrants. Entry is beneficial because innovations spill over to all parties (hence the positive support) but is also costly because the gains from entry have to be balanced off against the fixed entry cost that is associated with each entrant.<sup>17</sup> Since the regulatory agency cannot distinguish between the quality of entrants, in addition to these effects, overspill offers 'protection' to poor-quality entrants, making it harder for the regulator to blockade entry by inefficient firms. Furthermore, a potential information rent can accrue to better quality entrants whenever less good entrants are also sufficiently beneficial to be encouraged in some states of the world. The paper analyzes the implications on the market.

There are several issues that arise. One immediate policy question is whether the inability to identify good from bad entrants encourages the regulator to persist for longer in entry promoting strategies. We show that compared to the full information position, the regulator is less likely to do so. The set of cost parameters where there is potential for second period entry with incomplete information is a subset of the cases where there is full information. Similarly in the absence of full information, the set of cases where good and bad firms may simultaneously coexist in the market and the cases where the bad firm is 'priced into the market' are both subsets of the equivalent with full information.

There are two particularly interesting insights that we also highlight in the paper. One is that there exist entry profiles that are superior when only the entrants' incentives are considered but are not time consistent. This is interesting because of the type of inconsistency. A traditional inconsistency in a regulatory environment is that a regulator wishes to renege on a price cap. This is prevented here since we assume that the price cap

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<sup>16</sup> Such equilibrium exists even if the change incurs some cost to the good firm as long as the extra profit compensates it. In addition, an equilibrium also exists in which no change occurs because that is the common belief of the players.

<sup>17</sup> Spillovers may also have a negative effect by diluting incentives for individual companies to innovate. Note, although silent on the issue, the model does not necessarily assume that the negative impact on incentives that arise from spillovers are absent. Since we do not treat the extent of spillover as a variable in the paper (that is, it is constant throughout), one interpretation could be that diluted incentives are already embodied in the payoffs of the parties.

is legally contractible. The time consistency here concerns the number of firms that the regulator wants in the market. If the regulator could precommit to a regulatory entry policy, there are cases where he/she would wish to take an aggressive antientry policy (i.e., price the bad firm out of the market). However, when the regulator gets to this point (because the price cap has been fixed), he/she will then decide to take a liberal attitude to entry and adopt lower access prices to promote entry. Of course, this is foreseen by the incumbent who will reject the price cap since it is only profitable when entry is blockaded. This problem may have resonance for regulated companies, which often feel there is too much encouragement of entry into their markets. It is interesting to observe that there may be too much entry because regulators cannot escape the time inconsistency problem; that is, the regulators themselves encourage more entry than they would ideally wish. Another insight that arises is that there are many cost configurations where the good firm would be better off if their comparative advantage over the bad firm was smaller. The reason is that the good firm has an incentive to ‘keep the bad firm in the game’ to maximize information rent. We conjecture that this might lead to a form of dampened incentives that has not received focus.

The model used in the paper is of a simple form that enables us to focus cleanly on the central points that we have wished to make. An obvious question is then whether the central results depend on the specifics of the model. We finish the paper with a discussion of the robustness of the results.

The model enables an explicit association of entry profiles with underlying cost parameters for the full information and incomplete information cases. Clearly, the boundaries of these will be dependent on the specifics of the model. For example, if there is a possibility of having two good or two bad firms (as well as one of each) then for a given set of parameters, the cost of pricing a bad firm out of the market in the first period is greater than in the current model since a regulator can no longer be sure, given the absence of entry in the initial period, that the second period entrant will be good. This will impact on the cost configurations that favor entry by a bad firm in the first period. Furthermore, if we allow for market sizes that are small enough that the optimal price cap does not bind when both firms enter then, if entry costs are close to zero, the regulator is more likely to favor entry by a bad firm in the second period.<sup>18</sup> Also obviously, the time inconsistency results disappear if we allow the regulator to precommit on access prices.

However, the core results are very robust to such model specifications for the following reason. At the heart of our main results is a basic relationship when one compares the full information to the incomplete information setting. Any entry profile that prices out the bad entrant ( $A^0$ ,  $A^1$  and  $A^2$ ) involves no loss in welfare as we move from the full information to the incomplete information setup since the regulator does not have to worry that he/she cannot explicitly identify the quality of a potential entrant. In contrast, any profile that requires entry by the bad firm involves an information rent for the good firm. In this case, the good firm is taking an information rent out of the market, which has to be funded by the consumers in the market through higher prices, creating a welfare loss. Since there is a strict welfare loss in moving to the incomplete

<sup>18</sup> More formally  $A^4$  in Fig. 1 may contain a region  $A^5$  close to the left hand axis.

information setting whenever the regulator chooses to price bad firms into the market, at the margin, the regulator will tend to be less keen on this strategy than one that prices the bad firm out of the market (since there is no welfare loss in the latter case). The good firm can always act like a bad firm, so the existence of information rent and hence the distortion at the margin is likely to be extremely general and not dependent on the specifics of the model.

The above deals with all cases save when one compares entry profiles that involve limited entry of bad firms ( $A^3$ ) with profiles that have entry of the bad firm in both periods ( $A^5$ ). Here, a similar but more complex type of argument still applies since there is more information rent in  $A^5$  than in  $A^3$ . However, in this specific case, the particular assumption of *complete* spillover needs further discussion. If the spillover is less than complete, then the profile  $A^4$  is implementable even with incomplete information because the good and bad firms are different even when they coexist. It is still the case, though, that the good firm reaps an information rent in  $A^4$  when it arrives first (as well as in  $A^3$ ) because it has better technology and faces less competition than the bad firm who is also accommodated. Hence, the conclusion remains that the regions for  $A^3$  and  $A^4$  shrink due to incomplete information. However, how the boundary between  $A^3$  and  $A^4$  moves can be unclear. One can also consider the possibility that there are several potential types of innovations with differing spillovers. Then the  $A^5$  region may become probabilistic; that is, the  $A^5$  region could clearly be avoided in states of the world when the spillover is not complete, but the problem of complete protection of bad firms are likely to still hold in states of the world when the particular innovations that arise have complete spillover.<sup>19</sup> We believe that the innovations that arise from the kind of competition we are considering here may involve complete spillover (we think examples like the mobile phone one given in the introduction of the paper are not unknown). So even for the comparison of entry profiles that involve limited entry of bad firms with profiles that have entry of the bad firm in both periods, the insights we have identified in the paper are likely to be material. Therefore, overall, we are confident that the key insights of the paper are not dependent on the specifics of the model.

## Appendix A

### A.1. Proof of proposition 1

We derive a series of lemmas that together will prove Proposition 1. Recall the minimum price cap  $p^i(c, F)$  subject to the incentive compatibility constraint (2). Note that  $p^0$  is independent of both  $c$  and  $F$ , and  $p^1$  and  $p^2$  are functions of  $F$  only, so we may write  $p^i(F) = p^i(c, F)$  for  $i=1, 2$ . When no confusion arises, we use  $p^i$  as shorthand for  $p^i(c, F)$ .

Note also that the optimal price caps  $p^i(c, F)$  may not exist for higher levels of  $F$ . Since the LHS of Eq. (2) is assumed quasiconcave and the RHS is increasing in  $F$ , if  $p^i$  exists for some value of  $F$  then so it does for all smaller values of  $F$ . Given  $c$  let  $\hat{F}^i(c)$  denote the maximum value of  $F$  for which  $p^i(c, F)$  exists. Let  $\hat{F}^i(c) = \infty$  if  $p^i(c, F)$  exists for all  $F \in \mathbb{R}_+$ . Note that  $\hat{F}^0 = \infty$ .

<sup>19</sup> Although, exactly how this would work would depend on assumptions about what is known and when.

**Lemma A1.** *If  $\hat{F}^j(c) = \infty$  for some  $j \in \{1, 2, 3, 4\}$  and  $c \in (0, 1)$ , then  $\hat{F}^i(c) = \infty$  for all  $i \in \{0, 1, 2, 3, 4\}$  and all  $c \in (0, 1)$ .*

**Proof.** If  $\hat{F}^j(c) = \infty$  for some  $j \geq 1$  and  $c \in (0, 1)$ , then the LHS of Eq. (3) for  $A^j$ ,  $2(p - \bar{c}_j)D(p)$ , must be unbounded above. Since  $2(p - \bar{c}_j)D(p)$  is continuous, this means that  $\lim_{p \rightarrow \infty} 2(p - \bar{c}_j)D(p) = \infty$ . Note that  $2(p - \bar{c}_j)D(p) - 2(p - \bar{c}_i)D(p) = 2(\bar{c}_i - \bar{c}_j)D(p)$  and  $(\bar{c}_i - \bar{c}_j)\lim_{p \rightarrow \infty} D(p)$  is bounded for any  $\bar{c}_i$ . Therefore,  $\lim_{p \rightarrow \infty} 2(p - \bar{c}_i)D(p) = \infty$  as well, which establishes that  $\hat{F}^i(c) = \infty$  for all  $i$  and  $c \in (0, 1)$ .  $\square$

For  $i, j = 0, \dots, 4$ , we say that  $p^i$  *undercuts*  $p^j$  at a given  $(c, F)$  if the following holds: if  $p^j$  exists, so does  $p^i$  and  $p^i < p^j$ . The next lemma says that if a profile with more entry  $A^j$  meets incentive compatibility for higher levels of  $F$  than a profile with less entry  $A^i$ , then  $p^j$  always undercuts  $p^i$ .

**Lemma A2.** *If  $\hat{F}^i(c) < \hat{F}^j(c)$  for some  $i < j$  such that  $\{i, j\} \neq \{2, 3\}$ , then  $p^j$  undercuts  $p^i$  for all  $F \leq \hat{F}^j(c)$ .*

**Proof.** Suppose  $\hat{F}^i(c) < \hat{F}^j(c)$  for some  $i < j$ ,  $\{i, j\} \neq \{2, 3\}$ . Then,  $\hat{F}^i(c) < \infty$  and  $i > 0$  and by Lemma A1, therefore,  $\hat{F}^k(c) < \infty$  for all  $k \in \{1, 2, 3, 4\}$ . It suffices to show that  $p^j < p^i$  for all  $F \leq \hat{F}^i(c)$ . Let  $\bar{p}^k$  denote the smallest  $p$  such that  $2(p - \bar{c}_k)D(p) = \bar{e}_k \hat{F}^k(c)$ . Since  $\bar{c}_j < \bar{c}_i$  the derivatives of the LHS with respect to  $p$  are related as:

$$2D(p) - 2(p - \bar{c}_j)D'(p) < 2D(p) - 2(p - \bar{c}_i)D'(p) \tag{6}$$

as long as  $2(p - \bar{c}_j)D(p) > 0$  which is the case at all solution values  $p^i(c, F)$  that exists. Hence,  $2D(p) - 2(p - \bar{c}_j)D'(p) < 0$  at  $p = p^i(c, \hat{F}^i(c))$  because the RHS of Eq. (6) is 0 and consequently,  $\bar{p}^j < \bar{p}^i$  due to quasiconcavity. Let  $F' < \hat{F}^i(c)$  be such that  $\bar{p}^j = \bar{p}^i(c, F')$  (this  $F'$  is unique because the RHS of Eq. (6) is positive at  $p = \bar{p}^j$ ). Since  $p^j(c, F) < \bar{p}^j$  for all  $F < \hat{F}^j(c)$ ,  $p^j(c, F) < p^i(c, F)$  is obvious when  $F \in [F', \hat{F}^i(c)]$  because  $p^i(c, F) \geq \bar{p}^j$  for such  $F$ . For  $F < F'$ , note that  $2(\bar{p}^j - \bar{c}_i)D(\bar{p}^j) - 2(p^i(c, F) - \bar{c}_i)D(p^i(c, F)) = - \int_{\bar{p}^j}^{p^i(c, F)} [2D(p) - 2(p - \bar{c}_i)D'(p)] dp > - \int_{\bar{p}^j}^{p^i(c, F)} [2D(p) - 2(p - \bar{c}_j)D'(p)] dp = 2(\bar{p}^j - \bar{c}_j)D(\bar{p}^j) - 2(p^i(c, F) - \bar{c}_j)D(p^i(c, F))$ . Rearranging this inequality,

$$\begin{aligned} 2(p^i(c, F) - \bar{c}_j)D(p^i(c, F)) &> 2(\bar{p}^j - \bar{c}_j)D(\bar{p}^j) - 2(\bar{p}^j - \bar{c}_i)D(\bar{p}^j) \\ &+ 2(p^i(c, F) - \bar{c}_i)D(p^i(c, F)) > (\bar{e}_j - \bar{e}_i)F' + 2(p^i(c, F) - \bar{c}_i)D(p^i(c, F)) \\ &> (\bar{e}_j - \bar{e}_i)F + 2(p^i(c, F) - \bar{c}_i)D(p^i(c, F)) = \bar{e}_jF + L. \end{aligned}$$

Here, the second inequality follows because  $2(\bar{p}^j - \bar{c}_j)D(\bar{p}^j) - \bar{e}_jF' - L > 0 = 2(\bar{p}^j - \bar{c}_i)D(\bar{p}^j) - \bar{e}_iF' - L$ , the third inequality from  $F < F'$ , and the equality from definition of  $p^i(c, F)$ . This verifies that  $p^j(c, F) < p^i(c, F)$ .  $\square$

Given  $c$ , let  $F_{ij}(c)$  be the value of  $F$  such that  $p^i = p^j$  at  $(c, F_{ij}(c))$ . The next lemma shows inter alia that  $F_{ij}(c)$  is unique if exists, except for  $F_{23}(1/2)$  which is shown in Lemma A4 to be any  $F$  at which  $p^2(F)$  exists, because  $p^2(F) = p^3(1/2, F)$ .

**Lemma A3.** *Suppose  $\hat{F}^i(c) \geq \hat{F}^j(c)$  for  $i < j$  such that  $\{i, j\} \neq \{2, 3\}$ .*

- (a) *If  $F_{ij}(c)$  exists, then  $p^j < p^i$  for all  $F < F_{ij}(c)$  and  $p^j > p^i$  for all  $F \in (F_{ij}(c), \hat{F}^j(c)]$ .*
- (b) *If  $F_{ij}(c)$  does not exist, then  $p^j < p^i$  for all  $F < \hat{F}^j(c)$ .*

**Proof.** By supposition,  $p^i(c, F_{ij}(c)) = p^j(c, F_{ij}(c))$  which we denote by  $\hat{p}$  as shorthand, and  $\hat{p}$  solves two equations of Eq. (3):

$$(2p - 2\bar{c}_k)D(p) = \bar{e}_k F_{ij}(c) + L \quad (7)$$

for  $k=i, j$ , where  $(\bar{c}_i \geq \bar{c}_j$  and  $\bar{e}_i < \bar{e}_j$ ). Taking the differences between these two equations (valued at  $\hat{p}$ ) side by side, we get

$$2(\bar{c}_i - \bar{c}_j)D(\hat{p}) = (\bar{e}_j - \bar{e}_i)F_{ij}(c). \quad (8)$$

The LHS of Eq. (7) has a negative value at  $p=0$  and increases as  $p$  increases at least up to  $p^k(c, F_{ij}(c))$  for  $k=i, j$ , due to the quasiconcavity assumption. For  $F < F_{ij}(c)$ , therefore, both  $p^i(c, F)$  and  $p^j(c, F)$  exist and are smaller than  $\hat{p}$ . Moreover,  $p^j(c, F) < p^i(c, F)$  if the LHS of Eq. (7) for  $k=j$  assumes a larger value when evaluated at  $p=p^i(c, F)$  than at  $p=p^j(c, F)$ , i.e., if:

$$(2p^i(c, F) - 2\bar{c}_j)D(p^i(c, F)) > (2p^j(c, F) - 2\bar{c}_j)D(p^j(c, F)) = \bar{e}_j F + L \quad (9)$$

where the equality follows by definition of  $p^j(c, F)$ .

We now prove that  $p^j < p^i$  for all  $F < F_{ij}(c)$  by verifying Eq. (9). Note  $(2p^i(c, F) - 2\bar{c}_i)D(p^i(c, F)) = \bar{e}_i F + L$  by definition of  $p^i(c, F)$ . Adding  $2(\bar{c}_i - \bar{c}_j)D(p^i(c, F))$  on both sides, we get:

$$\begin{aligned} (2p^i(c, F) - 2\bar{c}_j)D(p^i(c, F)) &= \bar{e}_i F + L + 2(\bar{c}_i - \bar{c}_j)D(p^i(c, F)) > \bar{e}_i F + L + 2 \\ &\quad \times (\bar{c}_i - \bar{c}_j)D(\hat{p}) = \bar{e}_i F + L + (\bar{e}_j - \bar{e}_i)F_{ij}(c) > \bar{e}_i F \\ &\quad + L + (\bar{e}_j - \bar{e}_i)F = \bar{e}_j F + L. \end{aligned}$$

Here the first inequality follows from  $\hat{p} > p^i(c, F)$  and  $D'(p) < 0$ , the second equality from Eq. (8), and the second inequality from  $F < F_{ij}(c)$ . This proves Eq. (9), hence the first claim of part (a) of the Lemma.

For  $F > F_{ij}(c)$ , an analogous argument proves the second claim of part (a), that is, if  $p^j(c, F)$  exists, so does  $p^i(c, F)$  and  $p^i(c, F) < p^j(c, F)$ .

To prove part (b) of the Lemma, note that  $(2p - 2\bar{c}_j)D(p) > (2p - 2\bar{c}_i)D(p)$  when the latter is positive and, therefore,  $p^j(c, F) < p^i(c, F)$  for all sufficiently small  $F > 0$ . By continuity, therefore, this inequality always holds unless  $p^j(c, F) = p^i(c, F)$  for some  $F > 0$ , i.e., unless  $F_{ij}(c)$  exists.  $\square$

**Lemma A4.**  $p^2$  undercuts  $p^3$  at all  $(c, F)$  with  $c > 1/2$ ;  $p^2(F) = p^3(1/2, F)$  for all  $F$ ;  $p^3$  undercuts  $p^2$  at all  $(c, F)$  with  $c < 1/2$ .

**Proof.** The second assertion is immediate because the equations for  $A^2$  and  $A^3$  are identical if  $c=1/2$ . The first (last) assertion is easily verified because the LHS of the equation for  $A^2$  in Eq. (3) exceeds (falls short of) that for  $A^3$  while the right hand sides are the same.  $\square$

By Lemma A4, we need to compare  $p^0, p^1, p^2$  and  $p^4$  for  $c \geq 1/2$  and  $p^0, p^1, p^3$  and  $p^4$  for  $c \leq 1/2$ .

**Lemma A5.**

- (a) If  $F_{01}(c)$  exists,  $F_{01}(c) = 2D(p^0)$  for all  $c \in [0, 1]$ .
- (b) For  $c \in [1/2, 1)$ ,  $0 < F_{24}(c) < F_{12}(c) < F_{01}$  if these  $F_{ij}(c)$  exist;  $F_{24}(c)$  is continuous and decreases in  $c$  with  $\lim_{c \uparrow 1} F_{24}(c) = 0$ ;  $F_{12}(c)$  is a constant.
- (c) For  $c \in (0, 1/2]$ ,  $0 < F_{34}(c) < F_{13}(c) < F_{01}$  if these  $F_{ij}(c)$  exist;  $F_{34}(c)$  is continuous and increases in  $c$  with  $\lim_{c \downarrow 0} F_{34}(c) = 0$ ;  $F_{13}(c)$  is continuous and decreases in  $c$ .

**Proof.**

(a) The optimal price cap  $p^0$  for  $A^0$  is a constant. Since  $p^0$  also solves the second equation of Eq. (3) at  $(c, F_{01}(c))$ , part (a) follows easily.

(b) Let  $\hat{p}$  be the common solution to the second and third equations of Eq. (3) at  $F_{12}(c)$ . Multiply the former equation by 2 and subtract the latter side by side to verify that  $\hat{p}$  is a solution to  $(2p - 1.5)D(p) = L$ . In fact,  $\hat{p}$  is the smallest solution to this equation: otherwise  $\hat{p}$  would not be the smallest solutions to the second and third equations of Eq. (3), either. Obviously,  $\hat{p}$  is independent of  $c$ , and  $\hat{p} < p^0$  follows from  $(2p - 2)D(p) < (2p - 1.5)D(p)$ . Now, by taking differences between the second and third equations of Eq. (3), note  $F_{12}(c) = D(\hat{p})$ . So,  $F_{12}(c)$  is a constant. Furthermore,  $F_{12} < F_{01}$ : the value of the LHS of the second equation of Eq. (3) at  $\hat{p}$  is  $F_{12}/2 + L$  which is lower than that at  $p^0$ , namely,  $F_{01}/2 + L$ , because  $\hat{p} < p^0$  and the LHS is increasing up to  $p^0$ .

By an analogous argument,  $F_{24}(c) = (1 - c)D(\bar{p}) > 0$  where  $\bar{p}$  is the smallest solution to  $(2p + c - 1.5)D(p) = L$ . So,  $\bar{p} < \hat{p}$ . That  $F_{24}(c)$  is continuous and  $\lim_{c \uparrow 1} F_{24}(c) = 0$  is trivial. That it decreases in  $c$  can be shown by calculus, but an intuition suffices:  $A^4$  becomes less attractive than  $A^2$  for a larger  $c$ , which need be compensated by lower  $F$  so as to make  $A^4$  stay as attractive as  $A^2$ . Finally,  $F_{24}(c) < F_{12}$ : the value of the LHS of the third equation of Eq. (3) at  $\bar{p}$  is  $F_{24}(c) + L$  which is lower than that at  $\hat{p}$ , namely,  $F_{12} + L$ , because  $\bar{p} < \hat{p}$  and the LHS is increasing up to  $\hat{p}$ .

(c) The proof for part (c) consists of essentially the same (albeit slightly more involved) arguments as those used to prove part (b), which we omit here.  $\square$

**Lemma A6.**  $F_{ij}(c)$  is continuous on the domain on which it is defined.

**Proof.** First, we derive a technical implication of assumption [A1], namely, for all  $\bar{c} \in (0, 1)$  the derivative of  $2(p - \bar{c})D(p)$  is 0 only at the global maximum for  $p > \bar{c}$ . To see this, suppose otherwise, i.e., for some  $\hat{c} \in (0, 1)$  the derivative  $2pD(p) + 2(p - \hat{c})D'(p) = 0$  at  $p' > \hat{c}$  but  $2(p'' - \hat{c})D(p'') > 2(p' - \hat{c})D(p')$  for some  $p'' > \hat{c}$ . First consider the case  $p'' > p'$ . Note that  $2p'D(p') + 2(p' - \bar{c})D'(p') < 0$  for all  $\bar{c} < \hat{c}$ . Quasiconcavity, therefore, implies that  $2pD(p) + 2(p - \bar{c})D'(p) < 0$  for all  $p > p'$  if  $\bar{c} < c$ , hence there exist  $\epsilon, \delta > 0$  such that  $2(p'' - \bar{c})D(p'') < 2(p'' - \hat{c})D(p'') - \epsilon$  for all  $\bar{c} \in (\hat{c} - \delta, \hat{c})$ . Since this would contradict continuity of  $2(p - \bar{c})D(p)$  which implies  $\lim_{\bar{c} \uparrow \hat{c}} 2(p'' - \bar{c})D(p'') = 2(p'' - \hat{c})D(p'')$ , we proved the claim. The same conclusion can be obtained for the case  $p'' < p'$  by considering  $\bar{c} > \hat{c}$  analogously. Hence, we have proved that for all  $\bar{c} \in (0, 1)$  the function  $2(p - \bar{c})D(p)$  strictly increases until it reaches the maximum after which it strictly decreases. This implies for every  $i$  that  $p^i(c, F)$  is continuous where defined, hence so is

the total welfare level from inducing  $A^i$  at the minimum price cap subject to incentive compatibility and subgame optimality. The Lemma follows from the continuity of total welfare level and Lemma A3-(a).  $\square$

Now we conclude the proof of Proposition 1. Given  $c \in (0,1)$ , it is immediate from Eq. (3) that  $p^4$  undercuts all  $p^i$ ,  $i < 4$ , for sufficiently small  $F > 0$  because  $\bar{c}_4 < \bar{c}_i$  for  $i < 4$ , and that  $p^0$  undercuts all  $p^i$ ,  $i > 0$ , for sufficiently large  $F > 0$  because  $\bar{e}_0 = 0$  while  $\bar{e}_i > 0$  for  $i > 0$ . Note further that if  $p^j$  undercuts all other  $p^k$  at  $(c, F')$  then  $p^j$  is not undercut by any  $p^i$ ,  $i < j$ , at all  $(c, F'')$  such that  $0 < F'' < F'$ : Lemmas A2 and A3 establish that this indeed is the case when  $\hat{F}^i(c) < \hat{F}^j(c)$  and when  $\hat{F}^i(c) \geq \hat{F}^j(c)$ , respectively. In light of this observation, it is a routine exercise to verify the inequalities and first-best profiles claimed in the parts (a)–(c) of Proposition 1, by defining  $f_i$  on  $(0,1)$  as below for  $i = 1, 2, 3, 4$ .

For each  $c \in (0,1)$ , define  $f_4(c)$  to be the supremum of  $F$  such that  $p^4$  undercuts  $p^i$  for all  $i \in \{0,1,2,3\}$ . For each  $c \in [1/2,1)$ , define  $f_2(c)$  to be the supremum of  $F$  such that  $p^2$  undercuts  $p^i$  for all  $i \in \{0,1,3,4\}$ ; if the supremum does not exist (because  $A^2$  is never a unique first-best) for some  $c$ , let  $f_2(c) = f_4(c)$ . Analogously, for each  $c \in (0,1/2]$ , define  $f_3(c)$  to be the supremum of  $F$  such that  $p^3$  undercuts  $p^i$  for all  $i \in \{0,1,2,4\}$ ; if the supremum does not exist for some  $c$ , let  $f_3(c) = f_4(c)$ . For  $c = 1/2$ , let  $f_2(1/2) = f_3(1/2)$  be the supremum of  $F$  such that  $p^2(1/2, F) = p^3(1/2, F)$  undercuts  $p^i$  for all  $i \in \{0,1,4\}$ ; if the supremum does not exist for some  $c$ , let  $f_2(1/2) = f_3(1/2) = f_4(1/2)$ . For each  $c \in (0,1)$ , define  $f_1(c)$  to be the supremum of  $F$  such that  $p^1$  undercuts  $p^i$  for all  $i \in \{0,2,3,4\}$ ; if the supremum does not exist for some  $c$ , let  $f_1(c) = f_2(c)$  if  $c \geq 1/2$  and  $f_1(c) = f_3(c)$  if  $c < 1/2$ .

Finally, it remains to show that the functions  $f_i$  are continuous. It is clear from construction that the graph of  $f_i$  consists of segments of the graphs of some  $F_{ij}(\cdot)$  and/or  $\hat{F}^i(\cdot)$ , and that each endpoint of any such segment contained in the graph of  $f_i$ , unless the endpoint is an endpoint of the graph of  $f_i$  itself, is connected to another segment of such kind. Note that each  $F_{ij}(\cdot)$  is continuous by Lemma A6 and so is  $\hat{F}^i(\cdot)$  because the LHS of Eq. (3) is continuous in  $c$ . Hence, the continuity of  $f_i$  follows.

### A.2. Proof of theorem 2

Since  $(2p - c/2)D(p) \leq 3\hat{F}^4(c)/2 + L$  for all  $p > 0$  by definition of  $\hat{F}^4(c)$ , we have  $(2p - 3c/4)D(p) < 3\hat{F}^4(c)/2 + L < 2\hat{F}^4(c) + L$ . Letting  $\hat{F}^{*5}(c)$  denote the maximum  $F$  that satisfies the incentive compatibility (5) of  $A^5$  for given  $c$ , therefore, we have

$$\hat{F}^{*5}(c) < \hat{F}^4(c) \quad \text{for all } c \in (0,1). \tag{10}$$

In addition, for  $F \leq \hat{F}^{*5}(c)$ , the profile  $A^5$  cannot be implemented at a price cap less than  $p_*^5(c, F)$ , while from Theorem 1, we know that  $A^4$  can be implemented at a price cap  $p^4(c, F)$  under full information if  $A^4$  is the first-best profile. Since  $p^4(c, F) < p_*^5(c, F)$  and the additional entry in  $A^5$  relative to  $A^4$  does not reduce production cost, we have

**Lemma A7.** *If  $F \leq \hat{F}_*^5(c)$  and  $A^4$  is the first-best profile for  $(c, F)$ , then the total welfare from inducing  $A^4$  under full information exceeds that of inducing  $A^5$  under incomplete information.*

Let  $f_5^*(c)$  denote the supremum of  $F$  such that  $A^5$  is optimal for the regulator to implement under incomplete information. First, we prove Theorem 2 for  $c \in [1/2, 1)$  by showing that  $f_5^*(c) < f_4(c)$ . If  $f_4(c) = \hat{F}_4(c)$ , then  $f_5^*(c) < f_4(c)$  is clear from Eq. (10) because  $f_5^*(c) \leq \hat{F}_*^5(c)$ . Suppose alternatively, i.e.,  $f_4(c) < \hat{F}_4(c)$ . Then, from Lemmas A2 and A3, we deduce that  $A^4$  and another  $A^i$ ,  $i=0, 1, 2$ , are equivalent as first-best at  $(c, f_4(c))$ . If  $f_4(c) > \hat{F}_*^5(c)$ , again  $f_5^*(c) < f_4(c)$  is obvious. If  $f_4(c) \leq \hat{F}_*^5(c)$ , the welfare from  $A^5$  is lower than that of  $A^4$  under full information by Lemma A7, hence that of  $A^i$  which is equivalent to  $A^4$  under full information. Since  $A^i$  is implementable in the same manner under incomplete information by Lemma 3 and the welfare level from  $A^i$  is continuous,  $f_5^*(c) < f_4(c)$  ensues.

For  $c \in (0, 1/2)$  let  $\hat{F}_*^3(c)$  denote the maximum  $F$  that satisfies the incentive compatibility (4) of  $A^3$  under incomplete information; let  $f_3^*(c)$  denote the supremum of  $F$ , if exists, such that  $A^3$  is optimal for the regulator to implement under incomplete information. From comparing Eq. (4) with the fourth equation of Eq. (3),  $\hat{F}_*^3(c) < \hat{F}^3(c)$  is immediate. We now prove Theorem 2 for  $c \in (0, 1/2)$  by showing that  $f_3^*(c) < f_3(c)$  and  $f_5^*(c) < f_5(c)$ .

If  $f_3(c) = \hat{F}^3(c)$ , then  $f_3^*(c) \leq \hat{F}_*^3(c) < \hat{F}^3(c) = f_3(c)$  is immediate. If  $f_3(c) < \hat{F}^3(c)$ , by Lemmas A2 and A3 as before,  $A^3$  is equivalent to another profile  $A^i$ ,  $i=0, 1$ , as first-best at  $(c, f_3(c))$ . Recall that the welfare from  $A^3$  decreases due to incomplete information while that of  $A^i$  does not (cf. Lemma 3). Because  $A^i$  is implementable for  $F < f_3(c)$  and the welfare from it is continuous,  $f_3^*(c) < f_3(c)$  ensues.

We now show  $f_5^*(c) < f_4(c)$  for  $c \in (0, 1/2)$ . If  $f_4(c) = \hat{F}^4(c)$ , the inequality is clear once again by Eq. (10). Suppose alternatively, i.e.,  $f_4(c) < \hat{F}^4(c)$ , so that  $A^4$  is equivalent to another profile  $A^i$  as first-best at  $(c, f_4(c))$  where  $i \in \{0, 1, 3\}$ . If  $i=0$  or  $1$ ,  $f_5^*(c) < f_4(c)$  follows by the same argument as used above for  $c \in [1/2, 1)$ .

The rest of proof concerns the case  $i=3$ , in which case  $f_4(c) = F_{34}(c)$ . Let  $\tilde{p} = p^3(c, f_4(c)) = p^4(c, f_4(c))$ . As verified in Theorem 1, once  $\tilde{p}$  is accepted by the incumbent, both  $A^3$  and  $A^4$  are subgame-optimal for the regulator to induce under complete information. Since the consumers' surpluses are the same in both profiles, this means that the producers' surpluses are also the same: the cost saving due to additional entry in  $A^4$  is cancelled by the extra entry cost, i.e.,  $D(\tilde{p})c = f_4(c) \Leftrightarrow \tilde{p} = D^{-1}(f_4(c)/c)$ .

For  $A^5$  to be implementable under incomplete information, there must exist a price cap  $p$  that satisfies Eq. (5) and subgame optimality; that is, once  $p$  is accepted, the regulator indeed prefers to induce  $A^5$  to any other profile. This latter condition implies, in particular, that the producers' surplus is at least as high in  $A^5$  as in  $A^3$  given the price cap  $p$ , i.e.,  $D(p)c \geq 2F \Leftrightarrow p \leq D^{-1}(2F/c)$ .

Finally, we conclude the proof by showing that  $A^5$  is not implementable for  $F \geq f_4(c)$ . To implement  $A^5$  at  $F \geq f_4(c)$ , we would need  $p \geq p_*^5(c, F) \geq p_*^5(c, f_4(c)) > p^4(c, f_4(c)) = \tilde{p} = D^{-1}(f_4(c)/c)$  where the last equality is derived above. We also derived above that the subgame optimality condition would require  $p \leq D^{-1}(2F/c) < D^{-1}(f_4(c)/c)$ . Since  $p$  cannot satisfy both inequalities,  $A^5$  is not implementable for  $F \geq f_4(c)$ . Hence,  $f_5^*(c) < f_4(c)$  ensues. □

### A.3. Proof of Proposition 2

Pick a cost configuration  $(1/2, F)$  on the boundary between the first-best regions for  $A^2$  and  $A^3$  in Fig. 1. By Lemma 3,  $A^2$  can be implemented at  $(1/2, F)$  under incomplete information in the first-best way, i.e., with the first-best price cap  $p^2(1/2, F)$  and access prices, say  $a^1$  in period 1 and  $a^2$  and  $a'_2$  for period 2 for the contingencies of prior entry and no prior entry, respectively. Given this access-pricing strategy, (i)  $A^2$  is incentive compatible, and (ii) each entrant and the incumbent obtain zero expected surplus. Let  $W^*(1/2, F)$  be the first-best welfare level at  $(1/2, F)$ .

Consider a cost configuration  $(1/2 - \epsilon, F)$  for an arbitrarily small  $\epsilon > 0$ . Given the same access-pricing strategy, once the price cap  $p^2(1/2, F)$  is accepted,  $A^2$  is still incentive compatible at  $(1/2 - \epsilon, F)$ : the incentive of firm is the same as at  $(1/2, F)$ , and the  $b$  firm's expected surplus from entry may be slightly better than at  $(1/2, F)$  but still negative. The welfare from  $A^2$  at  $(1/2 - \epsilon, F)$  given this access-pricing strategy is slightly higher than  $W^*(1/2, F)$ .

Next, consider  $A^3$  at  $(1/2, F)$  under incomplete information. As argued earlier, the  $g$  entrant has a strictly positive information rent. To induce  $A^3$  with nonnegative surplus for the incumbent, therefore, the price cap should be higher than  $p^3(1/2, F)$ , hence the welfare from optimally inducing  $A^3$  at  $(1/2, F)$  is strictly lower than  $W^*(1/2, F)$ . By continuity, so is the welfare from optimally inducing  $A^3$  at  $(1/2 - \epsilon, F)$ . Thus, together with the discussion in the previous paragraph, given the configuration  $(1/2 - \epsilon, F)$ ,  $A^2$  is incentive compatible at the price cap  $p^2(1/2, F)$  and generates a higher welfare than optimally inducing  $A^3$  (an analogous argument applies when  $A^1$  is the optimal profile to induce at  $(1/2 - \epsilon, F)$  under incomplete information).

Note that for some other price caps close to  $p^2(1/2, F)$ , the latter claim about  $A^2$  still holds. We now show that for any such price cap  $p$ , once it is accepted by the incumbent, the regulator can enhance the welfare by inducing  $A^3$  instead of  $A^2$ . First, since the price cap is binding, the consumers surplus is the same between  $A^2$  and  $A^3$ , while the producers surplus is higher in  $A^3$  by the expected difference in production and entry costs, i.e., by  $D(p)1/2 - D(p)(1/2 - \epsilon) > 0$ . Hence, it only remains to show that it is indeed possible to induce  $A^3$  once  $p$  is accepted. Consider access prices as follows: set the period 2 access price in case of prior entry such that the  $g$  firm makes negative profit if it enters in period 2; given this period 2 access price, set the period 1 access price such that the  $b$  firm makes a zero expected profit if it enters in period 1 and the other firm does not enter in period 2. Given these access prices, it is clear that both types of firm will enter in period 1 and no firm enters in period 2; that is,  $A^3$  will be induced. This completes the proof.  $\square$

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