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Network investment and the threat of regulation – preventing monopoly exploitation or infrastructure construction? [1]

Abstract

In summer 2005, the German telecommunication incumbent Deutsche Telekom announced its plans to build a new broadband fibre optics network. Deutsche Telekom decided as precondition for this new network not to be regulated with respect to pricing and third party access. To develop a regulator's strategy that allows investments and prevents monopolistic prices at the same time, we model an incumbent's decision problem under a threat of regulation in a game-theoretical context. The decision whether to invest or not depends on the probability of regulation and its assumed impact on investment returns. Depending on the incumbent's expectation on these parameters, he will decide if the investment is favourable, and which price to best set. This price is below a non-regulated profit maximising price, since the incumbent tries to circumvent regulation. Thus, we show that the mere threat of a regulator's intervention might prevent supernormal profits without actual price regulation. The regulator, on the other hand, can influence both investment decision and the incumbent's price via his signals on regulation probability and price. These signals can be considered optimal, if they simultaneously allow investment and minimize the incumbent's price.

Keywords: regulation, investment, telecommunication, network industries

JEL classifications: L43,L51,L96

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Zusammenfassung

Im Sommer 2005 gab die Deutsche Telekom ihre Planungen für den Aufbau eines neuen Glasfaserbreitbandkabelnetzes bekannt. Sie stellte dabei zur Bedingung, daß dieses Netz weder preislich noch hinsichtlich des Netzzugangs Dritter reguliert werden sollte. Um eine Regulierungsstrategie zu definieren, die gleichzeitig die Investition ermöglicht und monopolistische Preise verhindert, wird in diesem Beitrag ein Modell entwickelt, das das Entscheidungsproblem des Marktsassen unter Regulierungsandrohung spieltheoretisch untersucht. Die Investitionsentscheidung ist dabei abhängig von der Regulierungswahrscheinlichkeit und dem Regulierungsumfang, mithin dem Einfluß der Regulierung auf die Einnahmen des Marktsassen. Auf Grundlage der Erwartungen des Marktsassen bezüglich dieser Parameter wird er entscheiden, ob er investiert und welchen Preis er wählt. Dieser Preis wird unterhalb eines unregulierten Preises liegen, um eine Regulierung abzuwenden. Folglich wird gezeigt, daß schon die Androhung der Regulierung Übergewinne verhindert, ohne daß der regulatorische Eingriff selbst tatsächlich erfolgen muß. Der Regulierer wiederum kann die Investitionsentscheidung ebenso wie den vom Marktsassen gesetzten Preis durch Signale über Regulierungswahrscheinlichkeit und -preis beeinflussen. Diese Signale werden als optimal angesehen, wenn sie gleichzeitig die Investition ermöglichen und den Preis des Marktsassen minimieren.

Keywords: Regulierung, Investitionen, Telekommunikation, Netzindustrien

1 Introduction

In summer 2005, Deutsche Telekom announced its plans to build a new broadband fibre optics network. The initial investment was said to be around 3 billion euros. However, Deutsche Telekom decided on the precondition for this new network not to be regulated with respect to pricing and third party access.

German regulation authorities announced their refusal to concede to Telekom's pressure. They suggested that Telekom and its competitors, mostly service providers that rent capacity from the dominant incumbent, agree on rules how to manage access to the new infrastructure. Following this Telekom let it be known that they were unwilling to share the new capacities with competitors, claiming that competitors should undertake the irreversible network investments (sunk costs) by themselves. Unless the new, technologically leading infrastructure were exempted from regulation, Telekom threatened the investment to be made in other areas or countries. Hence, the German regulator faced a difficult situation: Allowing Telekom to have its way would mean an end to traditional access regulation in telecommunication in Germany. However, if the regulator decided access regulation to hold, the infrastructure would not be set up.

In summary, the regulatory agency faced an issue of first and second degree errors: if it regulated an area which - from the economic point of view - should be left unregulated, such an over-regulation might foreclose welfare enhancing investments. If, however, it did not regulate an area which required regulation, under-regulation could inhibit competition and facilitate market power exploitation.

In this article we model an incumbent's decision problem under a threat of regulation in a game-theoretical context. The decision whether to invest or not depends on the probability of regulation and its assumed impact on investment returns. Depending on the incumbent's expectation on these parameters, he will decide whether the investment is favourable or not, and which price to best set. This price is below a non-regulated profit maximising price, since the incumbent tries to circumvent regulation and reduce the intervention probability, respectively. Thus, we show that the mere threat of a regulator's intervention might prevent supernormal profits without actual price regulation. The regulator, on the other hand, can influence both investment decision and the incumbent's price via his signals on regulation probability and price. These signals can be considered optimal, if they simultaneously allow investment and minimize the incumbent's price. Accordingly, wrong regulator's signals might prevent investments. Hence, we model an investment decision under uncertainty (of regulation) to develop a welfare maximizing regulation strategy.

Previous research on the relationship between investment and regulation has discussed either impacts of specific regulatory regimes or incentives of underinvestment due to policy uncertainty. Continuing research on dynamic efficiency issues of regulation discussed by Mandy & Sharkey (2003) and Littlechild (2003), a current work by Evans & Guthrie (2005) addresses the negative incentives on investment imposed by total element long run incremental cost (TELRIC) regulation, and finds that within such a framework a capital asset pricing model application identifies an allowed risk premium to be crucial for sustainable investments. Indeed, Evans and Guthrie's models give interesting insights into the investment incentives of specific regulatory regimes. Unfortunately, their models assume a universal service obligation as well as a general revenue regulation. A second strand of literature discusses policy uncertainty or - more specifically - regulators' ex-post opportunism (potential hold-up). Recent work on different network industries, for example Ishi & Yan (2004), Saphores *et al.* (2004) and Dobbs (2004) confirms the hypothesis of delayed infrastructure investments as addressed by Teisberg (1993), who showed that rational firms might delay investment when facing uncertain or asymmetric profit and loss restrictions. However, previous research on investment under regulation has not addressed welfare enhancing aspects of regulatory uncertainty, the issue of regulatory threats, which is basically the threat of governmental intervention in case of inadequate price levels. The political intention is the incumbents restricting their prices voluntarily (the so called light-hand regulation approach, for an overview on network industries see Haucap *et al.* 2006). Developed by Glazer & McMillan (1992), there have been numerous applications on different network sectors (for an example of the British airport sector see Starkie (2001), and Acutt & Elliott (2001) for the experiences of the UK electricity generation industry). Brunekreeft (2004) translates the idea of regulatory threat to the threat of ex-post antitrust intervention, finding that under certain conditions the latter can work in similar fashion and also induce a voluntary price cap. The work on regulation by threat of intervention has neglected, as yet, to emphasize its relevance for investment decisions in network sectors. The remainder of this paper will be structured as follows: the analytical background and model are presented in Section 2 followed by Section 3 which discusses the results and highlights policy implications and directions for future research.

2 Analytical background and model

Consider an incumbent owning a network that is subject to a third party access regulation. He faces the decision of an ex-ante profitable investment of enhancing his current or building up an entirely new network. The potential problem is that this infrastructure enhancement might be regulated in the future. What factors determine the incumbent's decision and what kind of risks does he have to bear?

Suppose the incumbent can choose to invest either $\hat{I}$ or nothing into a new, welfare enhancing infrastructure. The investment is necessary to sell a new service or good. Consequently, it increases market size and decreases pressure, allowing the skimming of innovation rents by the investor. In doing so, the incumbent faces certain risks, in particular the risk of being regulated once others have not invested being probably the most critical one.[2]

[2] Furthermore, the investing party has to bear the risks of technological obsolescence as well as simple economic default. We refrain from discussing these risks to reduce complexity, but it is clear that expected future profits have to cover these, too.

Initially, the incumbent has zero marginal costs and revenues $R = R(I, p)$, where $I \in \{0, \hat{I}\}$ denotes the new investment taken by the incumbent and p the price of the new good. The following characteristics apply to the revenue function:

- without investment ($I = 0$), revenues are independent of price, $\partial R(I = 0)/\partial p = 0$, and are equal to $R_0 = R\,(I = 0, p)$,
- with investment ($I = \hat{I}$), revenues are higher than without investment, $R_1(p) := R\left(I = \hat{I}, p\right) > R_0$ for $p > 0$,
- with investment ($I = \hat{I}$) and increasing price, revenues rise until p^*_{NR} (price of maximum turnover) and fall beyond that, $\frac{\partial R_1}{\partial p} \begin{cases} > 0 \text{ , if } p < p^*_{NR}, \\ = 0 \text{ , if } p = p^*_{NR}, \\ < 0 \text{ , if } p > p^*_{NR}. \end{cases}$

Therefore, in the case of investment $\hat{I}$, there is an optimal price p^*_{NR} for the incumbent assuming an unregulated benchmark case. The investment is welfare enhancing, and increases incumbent's profit without regulation threat, $R_1\left(p^*_{NR}\right) - \hat{I} > R_0$.

The regulator faces the dilemma between enabling the infrastructure investment and avoiding super-normal profits. More precisely, she has to define a regulation price p_R, which just covers the total investment cost. Under asymmetric information, she does not know which investments are essential for accessing new costumers, and which is the level of the efficient costs. Furthermore, there may exist real options that raise individual demand of the incumbent, and these are unknown to the regulator. Thus, she is unaware of the price and she can only signal her acceptance of prices within a certain tolerance bracket, with d expressing the distance between the regulation price and an intervention price $\overline{p}$. For any price p_1 choosen by the incumbent above that upper limit, the regulator will intervene with a probability of 1, setting the regulation price p_R. The regulator has the option to mask signals to a certain level. This signifies that tolerance can be ex-ante unknown to the incumbent. Such behaviour enables the regulator to make the incumbent reveal his true cost, at least to some extent. If the regulator signals the intervention price perfectly, the incumbent would invest, setting exactly that price or - in case of an unfavourable low intervention price - neglect the investment. Without perfect announcement, the incumbent might either invest and set a price which is above intervention price, making the regulator set the regulation price or, being threatened by a possible regulation, he might set a price which is below the intervention price. In both cases, the resulting price is lower than intervention price and is therefore welfare-enhancing. However, the investment under regulatory risk may be prevented, if the incumbent's perception of the intervention price is below a cost-covering level. Such an underinvestment should be just as well avoided as a monopoly exploitation by the incumbent, likewise.

A second and somewhat more specific problem is the possibility of a hold-up. In a static game, a regulator could signal an ex-ante investment allowing tolerance. After investment, she might hold up the incumbent by ex-post reducing her tolerance, identifying the incumbent's price as intolerably high and intervening by setting the regulation price. This price could be set welfare maximising, equal to marginal cost. Since the incumbent would anticipate such a lack of regulatory commitment he may refrain from investing. Therefore, we assume that the regulator commits to his signal via reputation and that no hold-up occur.

The incumbent builds up an expectation of the density function $f(d)$ of the regulator's tolerance interpreting her signals. We define $\sigma^2 = Var\,(d)$ as the variance of that tolerance. This variance increases with weakening signals. Since the incumbent has information/signals about the regulation price, he can estimate a density function over intervention price $f(\overline{p}) = f(d + p_R)$. Note that this intervention price is determined by the regulator. For any incumbent's price below that price (but above the regulation price), the regulator refrains from intervention, tolerating a certain deviation due to uncertainty. For any price above the intervention price, the regulator intervenes and sets the regulation price p_R. Recapitulating, the incumbent ex-ante knows the regulation price but neither the regulator's tolerance nor - thereby - her intervention price. Therefore, depending on the signals given, the incumbent can only derive a density function of that intervention price. For simplicity, we assume that density function to follow a symmetric triangular distribution:

$$f(\overline{p}) = \begin{cases} \frac{\overline{p}-p_R}{6\sigma^2} & \text{, if } p_R \leq \overline{p} \leq p_R + \sqrt{6}\sigma \\ \frac{p_R+2\sqrt{6}\sigma-\overline{p}}{6\sigma^2} & \text{, if } p_R + \sqrt{6}\sigma < \overline{p} \leq p_R + 2\sqrt{6}\sigma \\ 0 & \text{, if } \overline{p} < p_R \text{ or } \overline{p} > p_R + 2\sqrt{6}\sigma. \end{cases} \tag{1}$$

The incumbent hence expects the regulator to intervene with a probability of $F(p_1) = prob\,(\overline{p} \leq p_1)$, where p_1 is the incumbent's price after investment. That probability can be derived from the intervention price's density function and shows the following properties:

$$\begin{aligned} F(p_1) &= \int_0^{p_1} f(x)dx \\ &= \begin{cases} 0 & \text{, if } p_1 < p_R \\ \frac{(p-p_R)^2}{12\sigma^2} & \text{, if } p_R \leq p_1 \leq p_R + \sqrt{6}\sigma \\ 1 - \frac{\left(p_R+2\sqrt{6}\sigma-p\right)^2}{12\sigma^2} & \text{, if } p_R + \sqrt{6}\sigma < p_1 \leq p_R + 2\sqrt{6}\sigma \\ 1 & \text{, if } p_1 > p_R + 2\sqrt{6}\sigma. \end{cases} \end{aligned} \tag{2}$$

The expected intervention price $\overline{p}^e = p_R + \sqrt{6}\sigma$ increases in accordance with the regulation price p_R and with the regulator's tolerance, expressed by the variance of the density function σ^2. For a given incumbent's price the probability of intervention increases with a decreasing regulation price or tolerance. A perfect signal sets the variance of the expected tolerance to zero ($\sigma^2 = 0$) and equates expected intervention price with regulator's intervention price.

Figure 1 shows the relationship between the regulation price p_R, the intervention price's density function $f(\overline{p})$ and the probability of regulation $F(p_1)$.

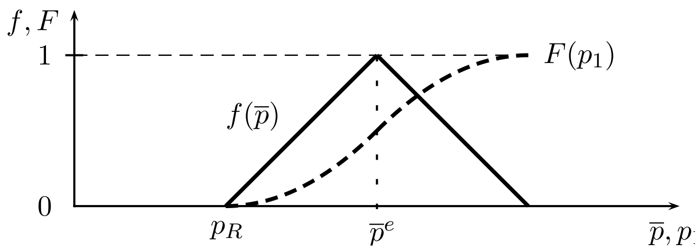

Figure 1: Intervention price density function and probability of regulation

The sequence of decision in the investment game is shown in figure 2. In a first step, the regulator gives a perfect signal about the regulation price p_R and a signal of her tolerance. Using that signal, the incumbent develops his expectation about the intervention price's density function $f(\overline{p})$; then he decides whether to invest or not. Deciding not to invest keeps him under normal regulation, providing a profit π_0. If he decides to invest, he will set a price p_1, causing the regulator to intervene or not.

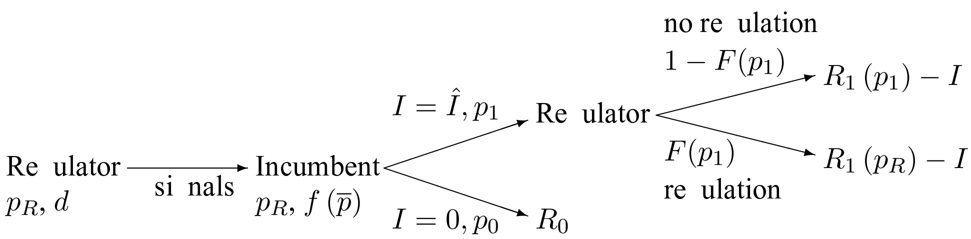

Figure 2: the model

A market with symmetric information

As a benchmark, we analyze an investment decision under symmetric information. If regulator knows about the total cost of investment, she is able to determine a minimum price p_1^{**} making the incumbent indifferent between investing and not, $R_0 = R_1(p_1^{**}) - \hat{I}$. To enable investment and minimize price afterwards, regulator sets p_1^{**} exactly, and sends a perfect signal on her (zero) tolerance. The incumbent receives that signal and calculates a probability function of regulatory intervention:

$$F(p_1) = \begin{cases} 0\text{ , if } p_1 \leq p_1^{**} \\ 1\text{ , if } p_1 > p_1^{**}. \end{cases}$$

The optimal price after investment is then $p_1^* = p_1^{**}$: a price $p_1 < p_1^{**}$ would have lower revenues and hence a profit lower than without investment R_0. A price $p_1 > p_1^{**}$ on the other hand would not be accepted and reduced to p_1^{**} by the regulator. Thus, in a market with symmetric information, where the regulator gives a perfect signal about the regulation price p_1^{**} and her tolerance of zero, the incumbent invests, setting exactly that price. With perfect information, potential regulation, i.e. the threat of regulation is equivalent to actually enforced regulation.

A regulated market

Under asymmetric information, the regulator faces the problem to decide which signal to give. To answer that question, we have to clarify the incumbent's incentives. His optimization problem is as follows:

$$\max_{I \in \{0, \hat{I}\}, p} \pi^e = \begin{cases} F(p) R_1(p_R) + (1 - F(p)) R_1(p) - I & \text{, if } I = \hat{I}, \\ R_0 & \text{, if } I = 0, \end{cases} \tag{3}$$

where π^e is the incumbent's expected profit, influenced by the incumbent's investment decision and his price. We denote p_1^* as his optimal price under investment. The first order condition for the incumbent in case of investment is

$$f(p_1^*) \left[R_1(p_R) - R_1(p_1^*) \right] + (1 - F(p_1^*)) \frac{\partial R_1}{\partial p} (p_1^*) \stackrel{!}{=} 0.$$

This can be rewritten as

$$(1 - F(p_1^*)) \frac{\partial R_1}{\partial p} (p_1^*) = \frac{dF(p_1^*)}{dp_1^*} \left[R_1(p_1^*) - R_1(p_R) \right]. \tag{4}$$

A price increase would lead to a revenue increase with a probability $1 - F(p_1^*)$ (left hand side of equation (4)), and hence an increase in expected revenues.[3] In equilibrium, that increase has to be equal to an expected increased drop in profit due to regulation (right hand side of equation (4)).

As shown for the market with symmetric information, the price p_1^{**} is defined as the break even investment (minimum) price with $R_0 = R_1(p_1^{**}) - \hat{I}$. Since revenues increase for any price $p_1^{**} < p < p_{NR}^*$, a rational investor invests, if the optimal price under investment is greater than that minimum price $p_1^* > p_1^{**}$.

Proposition *An incumbent's optimal price under investment in case of price regulation is*

– $p_1^* = p_{NR}^*$ *for* $p_R \geq p_{NR}^* \rightarrow F(p_{NR}^*) = 0$ *or*

[3] Note that in case of regulation revenues are independent of that price.

– *in range* $p_1^* \in \left[p_R, \min\left\{p_R + \sqrt{6}\sigma, p_{NR}^*\right\}\right]$ *with the following characteristics* $\partial p_1^*/\partial p_R > 0$ *and* $\partial p_1^*/\partial\sigma > 0$ *for* $p_R < p_{NR}^*$.

In the second case the incumbent's expected profits under investment increase with an increasing regulation price and a higher regulator's tolerance.

Proposition shows that the incumbent's optimal price is lower than the expected intervention price. Realistically, this price lies below the incumbent's profit maximising price in the absence of regulation (Cournot price).[4] Since the incumbent's optimal price (and - through that - his profit) is a function of p_R and σ, it rises with an increasing regulation price as well as an increasing tolerance.

For the regulator, the results from the proposition indicate that once uncertainty about the actual characteristics of the investment increases, she should either raise the regulation price or signal an increasing tolerance with respect to upward deviations from that price. However, the better the regulator is informed, the lower she may set the tolerance and the closer he can place the regulation price to the minimum investment enabling price p_1^{**}.

In such a setting, actual regulation becomes unnecessary. The mere threat of regulation prevents monopolistic prices while it allows profitable investment - if her signals are not to restrictive and therefore foreclosing.

3 Conclusions

This paper has modelled the trade-off a regulator faces when an incumbent intends to invest into a new welfare enhancing infrastructure. On the one hand, the regulator tries to anticipate market-power exploitation, on the other hand she has to consider that the threat of intervention may prevent the investment. Our model shows that the more the regulator's uncertainty about the lowest investment-permitting price increases, the more she should signal an increased tolerance against deviations from that regulation price. This indeed raises the intervention price and, consequently, the incumbent's profits. Nevertheless, the mere threat of a regulatory intervention might make an incumbent set a tolerable price even without actual price regulation. Given the corresponding limitation of abuse of market-power, ex-ante tolerance of super-normal profits can, from a welfare economic perspective, be considered to be preferable compared to the preventing of the investment. Moreover, the regulator could reduce thereby information asymmetries and decrease the optimal level of tolerance, resulting in a more precise intervention price and an effective regulatory threat. Recapitulating our findings, one could state that as long as the regulator is uncertain about cost and demand structure in the market of the infrastructure to be

[4] Only if the regulator overestimates the cost of investment or underrates the expected revenues and therefore sets a regulation price above the incumbent's unregulated optimal price, cournot charging would be favourable to setting the regulation price.

enhanced, she should not be acting too intolerantly, since such behaviour might prevent a welfare increasing investment. These results are consistent with previous research on the effectiveness of regulatory threats in particular. Concerning the case of Deutsche Telekom, the German regulator should - ex ante - leave the infrastructure investment unregulated and signal the regulation price. This should encourage Deutsche Telekom to invest while preventing it from exploiting its monopolistic power. From a dynamic perspective, such a light-handed regulation might encourage additional - and competitive - infrastructure investment, increasing technological development, economic welfare and making regulation redundant in the future. These results are consistent with previous research on the effectiveness of regulatory threats in particular. Therefore, our findings show that the concept of regulating by the threat of intervention is not only applicable to existing infrastructure but also to new investments as well.

This work described a regulator's optimal strategy concerning welfare enhancing infrastructure investments in a static game-theoretic setting, showing that the mere threat of regulation may be preferred to an actual regulatory intervention. Future research should analyse the effectiveness of regulatory threat on investment in a dynamic context. Additionally, demand risks could be introduced to model a more realistic investment decision. Over and above, further models should allow continuous investments and address the issue of regulation-investment sensitivity.

4 Appendix

Proof of proposition

Incumbent's optimal price

Case 1, $p_R \geq p^*_{NR}$*:* This situation is comparable to that without regulation threat. Thus, the optimal price is $p^*_1 = p^*_{NR}$.

Case 2, $p_R < p^*_{NR}$*:* We show by contradiction, that $p^*_1 \leq p^*_{NR}$, in a second part, that $p^*_1 \leq p_R + \sqrt{6}\sigma$ and in a third part, that $p^*_1 \geq p_R$.

I $p^*_1 \leq p^*_{NR}$*:* If we assume, that $p^*_1 > p^*_{NR}$, p^*_{NR} would increase profits:

$$\begin{aligned}\pi_1(p^*_1) &= F(p^*_1)R_1(p_R) + (1 - F(p^*_1))R_1(p^*_1) - I \\ &< F(p^*_{NR})R_1(p_R) + (1 - F(p^*_{NR}))R_1(p^*_{NR}) - I = \pi_1(p^*_{NR}),\end{aligned}$$

because

$$[F(p^*_1) - F(p^*_{NR})]\,[R_1(p_R) - R_1(p^*_{NR})] - [1 - F(p^*_1)]\,[R_1(p^*_{NR}) - R_1(p^*_1)] < 0.$$

This indeed is a contradiction and hence $p^*_1 \leq p^*_{NR}$.

II $p_1^* \leq p_R + \sqrt{6}\sigma$*:* If we assume, that $p_1^* > p_R + \sqrt{6}\sigma$, than equation 3 in conjunction with equation 1 can be written as following:

$$\frac{p_R + 2\sqrt{6}\sigma - p_1}{6\sigma^2}\left[R\left(p_R\right) - R\left(p_1\right)\right] + \frac{\left(p_R + 2\sqrt{6}\sigma - p_1\right)^2}{12\sigma^2}\frac{\partial R_1}{\partial p_1} = 0,$$

$$R\left(p_R\right) + \frac{p_R + 2\sqrt{6}\sigma - p_1}{2}\frac{\partial R_1}{\partial p_1} = R\left(p_1\right).$$

That equation can't be hold, because:

$$R\left(p_1\right) = R\left(p_R\right) + \int_{p_R}^{p_1}\frac{\partial R}{\partial x}dx > R\left(p_R\right) + \left(p_1 - p_R\right)\frac{\partial R}{\partial x}$$

$$> R\left(p_R\right) + \frac{p_R + 2\sqrt{6}\sigma - p_1}{2}\frac{\partial R}{\partial x}.$$

This is a contradiction and hence $p_1^* \leq p_R + \sqrt{6}\sigma$.

III $p_1^* \geq p_R$*:* As $p_R < p_{NR}$, a $p_1^* < p_R$ cannot be an optimum, because $\partial R_1/\partial p_1^* > 0$.

Reaction of the incumbent's optimal price

To proof the reaction of the incumbent's optimal price, we us the *implicit function theorem*. We write (4) as:

$$g := f\left(p_1^*\right)\left[R_1\left(p_R\right) - R_1\left(p_1^*\right)\right] + \left(1 - F(p_1^*)\right)\frac{\partial R_1}{\partial p_1}\left(p_1^*\right) \overset{!}{=} 0.$$

At first, we will proof that $\partial g/\partial p_1^* > 0$ and after that, we look how g reacts to p_R and d.

Reaction of g *to* p_1^* *:* We know that $p_1^* \leq p_R + \sqrt{6}\sigma$. Thus,

$$\frac{\partial g}{\partial p_1^*} = \overbrace{\frac{df}{dp_1}\left(p_1^*\right)\left[R_1\left(p_R\right) - R_1\left(p_1^*\right)\right]}^{\leq 0} - \overbrace{2f(p_1^*)\frac{\partial R_1}{\partial p}\left(p_1^*\right)}^{\geq 0} + \overbrace{\left(1 - F(p_1^*)\right)\frac{\partial^2 R_1}{\partial p_1^2}\left(p_1^*\right)}^{<0} < 0.$$

Change in expectations regarding the regulating price :

$$\frac{\partial g}{\partial p_R} = \overbrace{\frac{\partial f}{\partial p_R}\left(p_1^*\right)\left[R_1\left(p_R\right) - R_1\left(p_1^*\right)\right]}^{\geq 0} + \overbrace{f(p_1^*)\frac{\partial R_1}{\partial p_R}\left(p_R\right)}^{\geq 0} - \overbrace{\frac{\partial F}{\partial p_R}(p_1^*)\frac{\partial R_1}{\partial p_1}\left(p_1^*\right)}^{\leq 0} > 0.$$

That leads to $\partial p_1^*/\partial p_R = -\frac{\partial g}{\partial p_R}\Big/\frac{\partial g}{\partial p_1^*} > 0$.

Change in the expected tolerance :

$$\frac{\partial g}{\partial \sigma} = \overbrace{\frac{\partial f}{\partial \sigma}\left(p_1^*\right)\left[R_1\left(p_R\right) - R_1\left(p_1^*\right)\right]}^{\geq 0} - \overbrace{\frac{\partial F}{\partial \sigma}\left(p_1^*\right)\frac{\partial R_1}{\partial p_1}\left(p_1^*\right)}^{\leq 0} > 0$$

Thus, $\partial p_1^*/\partial \sigma = -\frac{\partial g}{\partial \sigma}\Big/\frac{\partial g}{\partial p_1^*} > 0$.

Reaction of expected profit by an increase of the regulation price

We define p_1^{*1} as the price choosen by the incumbent and π_1^{e1} as the expected profit in case of the regulation price p_R^1 and p_1^{*2} as the price choosen by the incumbent and π_1^{e2} as the expected profit in case of the regulation price p_R^2 with $p_R^1 < p_R^2$. The following can be reasoned:

$$\begin{aligned}
\pi_1^{e1}(p_1^{*1}) =& F^1(p_1^{*1})R_1(p_R^1) + (1 - F^1(p_1^{*1}))R_1(p_1^{*1}) - I \\
\leq& F^2(p_1^{*1})R_1(p_R^1) + (1 - F^2(p_1^{*1}))R_1(p_1^{*1}) - I \\
<& F^2(p_1^{*1})R_1(p_R^2) + (1 - F^2(p_1^{*1}))R_1(p_1^{*1}) - I \qquad =\pi_1^{e2}(p_1^{*1}) \\
& \qquad \leq \pi_1^{e2}(p_1^{*2}),
\end{aligned}$$

because of $\partial F/\partial p_R \leq 0$, $R_1(p_R^1) < R_1(p_1^{*1})$ and $R_1(p_R^1) < R_1(p_R^2)$.

Reaction of expected profit by an increase of the regulator's tolerance

We define p_1^{*1} as the price choosen by the incumbent and π_1^{e1} as the expected profit in case of the expected tolerance σ^1 and p_1^{*2} as the price choosen by the incumbent and π_1^{e2} as the expected profit in case of the expected tolerance σ^2 with $\sigma^1 < \sigma^2$. The following can be reasoned:

$$\begin{aligned}
\pi_1^{e1}(p_1^{*1}) =& F^1(p_1^{*1})R_1(p_R) + (1 - F^1(p_1^{*1}))R_1(p_1^{*1}) - I \\
\leq& F^2(p_1^{*1})R_1(p_R) + (1 - F^2(p_1^{*1}))R_1(p_1^{*1}) - I \qquad =\pi_1^{e2}(p_1^{*1}) \\
& \qquad \leq \pi_1^{e2}(p_1^{*2}),
\end{aligned}$$

because of $\partial F/\partial \sigma \leq 0$ and $R_1(p_R) < R_1(p_1^{*1})$.

□

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