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Compulsory Licensing, Innovation and Welfare*

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Abstract

This paper investigates the welfare effects of compulsory licensing, taking into account both static (information sharing) and dynamic (innovation) effects. Compulsory licensing is shown to have a positive impact on consumer surplus. Compulsory licensing has an ambiguous effect on total welfare, but is more likely to increase total welfare in industries which are naturally less competitive. Furthermore, compulsory licensing can be an effective policy to safeguard competition *per se*. These welfare results hold when R&D incentives favour the leading firm ('persistent dominance') and when they predict that the follower will overtake the incumbent ('action-reaction').

JEL: D43, D92, L13, O31, O34, O38

Keywords: compulsory licensing, competition policy, innovation, welfare

1 Introduction

It is well known that the unregulated exploitation by firms of their intellectual property (IP) rights can limit competition.¹ This paper focuses on a particular example of such behaviour: the unilateral refusal by a dominant firm to license its IP. As with the broader class of anticompetitive actions known as 'refusals to deal', such a refusal to license may be deemed an abuse of dominance on the basis of the anticompetitive harm that it generates. In such circumstances, a competition authority may impose a compulsory licence – a legal obligation to share IP in exchange for fair, reasonable and non-discriminatory (or FRAND) compensation² – in order to promote competition in the market. This was the course of action adopted by the European

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¹See, for example, Pate [2003].

²This is a rather vague notion, there being no formal guidance on the determination of FRAND prices. See, for example, O'Donoghue and Padilla [2006].

Commission, for example, when it ordered *Microsoft* to share interoperability information relating to its server technology with rival firms in 2004.³ Nevertheless, the high profile *Microsoft* case notwithstanding, there have been very few instances in which compulsory licensing was imposed, and none (to our knowledge) in the US.⁴ Of course the argument against compulsory licensing is that, by undermining the IP protection of innovating firms, it reduces firms' incentives to innovate.⁵ It follows that the welfare impact of compulsory licensing is, in principle, ambiguous, since it promotes competition only at the expense of reduced innovation incentives. While this paper confirms these conflicting effects, it also identifies two important cases in which the imposition of compulsory licensing is unambiguously welfare enhancing: (i) when the relevant welfare measure is consumer surplus and (ii) when it is total welfare, provided the industry in question is sufficiently uncompetitive.

The economic literature on the effects of compulsory licensing remains limited todate.⁶ In terms of the effect of compulsory licensing on innovation incentives, both Gilbert and Shapiro [1996] and Kühn and Van Reenen [2008] argue that compulsory licensing is likely to reduce R&D incentives, at least at the level of the firm which is obliged to license, if not at the industry level. Accordu and Akcigit [2012] show that compulsory licensing can actually induce a positive incentive effect in a dynamic model, due to what the authors term a "trickle-down" effect – the idea that optimally designed IP policies should offer stronger protection for leading firms in order to promote R&D spending by followers attempting to catch up. While this is an interesting theoretical result, it is rather difficult to relate it to the current policy context, given that the refusal to license offence is considered a potential abuse of dominance, implying that compulsory licensing weakens the IP protection of leading firms only. Moreover, given the very limited number of rulings implementing compulsory licensing in practice, it appears that policy makers do perceive there to be a cost to implementing such a policy, suggesting that the negative incentive effects should be taken seriously.

In terms of welfare, Tandon [1982] derives the optimal patent structure for innovations subject to compulsory licensing, and presents computations to suggest that compulsory licensing may be welfare enhancing in that context. Given that the welfare question is not the primary focus of that paper, several important issues – such as technological uncertainty, explicit competition at the innovation stage and the potential for voluntary licensing – are not considered in the analysis. More recently, Stavropoulou and Valletti [2013] have shown that compulsory licensing can be welfare enhancing, despite reducing the incentives to innovate, in the context of a North-South model of pharmaceutical trade (a framework quite distinct from that

 $^{^{3}}Microsoft$ was also ordered to pay a fine of c. €500 million.

⁴See American Bar Association [2003] for a useful summary of cases.

⁵Feldman [2009], Rozek [2000]

⁶Issues relating to the incentives to license innovations *voluntarily* and associated R&D effects have been discussed extensively in the literature, however. See Creane [2009], Rey and Salant [2012], Katz and Shapiro [1985, 1986, 1987], Sen and Tauman [2007], Gallini and Winter [1985] and Gallini [1984], amongst others.

developed here). Using another North-South model, Bond and Saggi [2012] show that compulsory licensing may either increase or decrease global welfare, depending on its impact on the entry decisions of patent-holding firms.⁷

This paper contributes to the emerging welfare literature by developing a general analysis of the static and dynamic effects of compulsory licensing. The welfare analysis is carried out in the context of both a consumer surplus and a total welfare standard, as well as in the case where the competition authority cares about protecting competition per se under a so-called foreclosure standard.⁸ We further allow for the behaviour of firms to differ according to prevailing industry R&D dynamics. While incumbency brings higher profits in a static sense, it may in general be either advantageous or disadvantageous in the sense of dynamic R&D competition. When innovation incentives favour the incumbent, we say we are in a 'persistent dominance' setting, since the leading firm is predicted to strengthen its dominant position via innovation. But it may also be true that innovation incentives favour the less efficient firm, and that successful innovation allows it to acquire the technological lead in the market, a scenario referred to as 'action-reaction'.⁹ It is important to determine whether the incentives for dominant firms to refuse to license and the associated anticompetitive harm carry over to the action-reaction setting, in which the dominance of the incumbent firm is, at least in the dynamic sense, weaker.¹⁰

We find that dominant firms do face incentives to refuse to license under both persistent dominance and action-reaction. In both scenarios, compulsory licensing leads to a fall in aggregate innovation spending. Nonetheless, under persistent dominance, compulsory licensing increases consumer surplus, even when dynamic effects are taken into account, because it guarantees that the most preferred consumer surplus outcome is realised. In terms of total welfare, the effect of compulsory licensing is ambiguous, but it is more likely to be positive when the industry in question is naturally less competitive. Compulsory licensing is also shown to equalise the innovation incentives of the firms, which in turn implies that it will be an effective tool to protect the competitive process *per se* under a foreclosure standard. In the action-reaction setting, the effects of compulsory licensing on R&D are quite different – most importantly the innovation incentives of the firms are no longer equalised. Nevertheless, all the welfare results go through (subject to one additional minor assumption).

The remainder of the paper is organised as follows. The following section outlines the model. Section 3 investigates the implications of compulsory licensing for both

⁷Katsoulacos [2008] addresses the related question of which legal standard is appropriate for refusals to license IP.

⁸The most common position in practice is for competition authorities to follow a consumer surplus standard (two exceptions are Canada and New Zealand, which follow a total welfare standard).

⁹This follows Beath *et al.* [1995]. Carlton and Gertner [2002] argue that most R&D-intensive industries, such as the IT, pharmaceutical and chemical industries, are characterised by action-reaction competition.

¹⁰If they did not, one solution to the refusal to license problem would be to promote policies aimed at generating action-reaction, rather than implementing compulsory licensing directly.

innovation incentives and welfare in a persistent dominance setting, while Section 4 considers the action-reaction case. Section 5 concludes.

2 The Model

We analyse a three-stage model of innovation, fixed-fee licensing and production.

Stage 1 – Innovation

Consider a technology race defined in terms of a cost or quality gap, in which the gap is measured relative to the existing industry standard. Suppose there are just two firms: the follower has the technology which defines the existing industry standard, while the leader has a product or technology which is ahead of this industry standard as a result of some previous innovation, to be understood in the sense of lower cost or higher quality. We write these gaps in the initial position as $g_F = 0$ and $g_L = G$, $0 \le G \le 1$, for the follower and leader, respectively, where the maximum conceivable gap has been normalised to 1. Firms are racing to be the first to discover a new technology that, for whoever is the first to discover, will increase their gap over the industry standard by the amount g, $0 \le g \le 1 - G$.

The competitive aspect of the firms' R&D decisions is captured in a tournament model of R&D. Firms select a hazard rate (instantaneous innovation probability, conditional on no firm having innovated up to that point) to maximise their expected discounted future profits. We assume that R&D costs are quadratic, which implies that the choice of a hazard rate is equivalent to a choice of R&D expenditure. Let the hazard rate chosen by the leader be denoted by x and that of the follower by y; $x, y \geq 0$. Writing the flow rate of profits earned in the product market as the result of winning the innovation race, losing the innovation race and under the status quo as π^W, π^L and π^0 , respectively, with $\pi^W > \pi^0 > \pi^L$, Beath *et al.* [1989] show that the competitive choices firms make over hazard rates are determined by two factors. Firstly, the competitive threat – denoted $CT_k, k = L, F$ – is a strictly increasing function of the difference $(\pi^W - \pi^L)$ between the profits from winning and losing the race. Secondly, the *profit incentive* is a function of the difference $(\pi^W - \pi^0)$ between the profits from winning the innovation race and under the status quo. Under certain weak conditions (which are assumed to hold throughout) the competitive threat will be the dominant factor determining firms' R&D spending.¹¹ For this reason, and for the sake of clarity, we focus on the competitive threat as the dominant factor in firms' innovation decisions.

Assumption 1. The outcome of the innovation race is determined by the relative magnitudes of the competitive threats.

¹¹The necessary and sufficient condition for the competitive threat to be greater than the profit incentive is $(\pi^L - \pi^0) < \left[\frac{\pi^W - \pi^L}{2r}\right]^2$, where r is the exogenous risk-free interest rate. This is always satisfied for r sufficiently small, for example.

It is also straightforward to show that the equilibrium R&D spending of the firms is increasing in the competitive threats of *both* firms. This justifies the following assumption.¹²

Assumption 2. Consider two equilibria in hazard rates (x^1, y^1) and (x^2, y^2) with corresponding competitive threats (CT_L^1, CT_F^1) and (CT_L^2, CT_F^2) . If $(CT_L^1, CT_F^1) > (CT_L^2, CT_F^2)$ then $(x^1, y^1) \gg (x^2, y^2)$.

These assumptions will allow us to translate results in terms of competitive threats into actual R&D spending implications.

Stage 2 – Fixed Fee Licensing

In order for compulsory licensing to be a meaningful policy, it must be the case that not all firms decide to license their innovations voluntarily. Several papers have shown that precisely such an equilibrium involving full diffusion of innovations will result when licensing is based (in whole or in part) on per-unit royalties.¹³ Hence, in order for the refusal to license problem to arise, it is necessary to assume that licensing is based on fixed fees only. In our model, firms bargain over the licence fee at which the technology is shared, and this is assumed to result in a Pareto-efficient outcome. This implies licensing will only occur voluntarily if it increases the firms' joint profits. We define compulsory licensing as a licensing deal that is (i) imposed by the competition authority when voluntary licensing is not feasible and (ii) priced below the maximum willingness to pay of the licence purchaser (FRAND).

Stage 3 – Production

The nature of competition in the product market will be treated quite generally. The following assumptions are consistent with homogeneous-product Cournot competition, though they may also be true more widely. Let $\pi(g_{\alpha}, g_{\beta})$ denote the operating profits made by a firm with gap g_{α} , $0 \leq g_{\alpha} \leq 1$, when its rival has a gap g_{β} , $0 \leq g_{\beta} \leq 1$. Assume this satisfies $\partial \pi/\partial g_{\alpha} > 0$ and $\partial \pi/\partial g_{\beta} < 0$. Let $\Sigma(g_{\alpha}, g_{\beta}) \equiv \pi(g_{\alpha}, g_{\beta}) + \pi(g_{\beta}, g_{\alpha})$ denote industry profits when one firm has a gap g_{α} while the other has a gap g_{β} . It is a standard property of Cournot equilibria that the equilibrium price, aggregate output and hence consumer surplus depend only on the average gap, and so, effectively, on the combined gap $g_{\alpha} + g_{\beta}$. Consequently, in what follows, it is assumed that consumer surplus is a strictly increasing function of the combined gap, denoted by $CS(g_{\alpha} + g_{\beta})$ with CS' > 0. In certain industries, it may be possible for the leader to foreclose the follower by opening up a sufficiently large lead. Where foreclosure is a possibility, we define the 'foreclosure margin' \hat{g} as

 $^{^{12}}$ In Appendix A we show that these assumptions are satisfied in a setting where the profit incentive has been normalised to zero.

 $^{^{13}}$ See Kamien and Tauman [1986] and Kamien *et al.* [1992] for licensing based purely on royalties, and Sen and Tauman [2007] for the case of optimally combined fixed fees and royalties.

the critical value of the leader's advantage over the follower, such that the follower will be forced out of the market if and only if $g_L - g_F > \hat{g}$.

In Appendix B we develop a homogeneous-product Cournot benchmark (comprising both a general demand environment and a specific linear demand example), which allows us to relate the results of the model to two measures of industry competitiveness: the Herfindahl index and demand elasticity. Further discussion of the Cournot benchmark is contained in Appendix B. In what follows the variable z_k^{js} will denote the value of variable z that accrues to firm k = L, F if the winner of the race is firm j = L, F, and if the degree of information sharing is s = N, V, C, where N denotes no licensing, V denotes a voluntary licensing regime and C denotes compulsory licensing. If a variable z is written without subscript k, it accrues to society as a whole rather than to either of the firms.

3 Persistent Dominance

Under persistent dominance, the leader is the predicted winner of the innovation race. This section first shows that the model outlined in Section 2 implies persistent dominance, before deriving firms' R&D behaviour in the benchmark case of voluntary licensing. We then analyse the effects of compulsory licensing on innovation incentives and welfare. Both under a consumer surplus and foreclosure standard, compulsory licensing is shown to be a beneficial policy. Its effect on total welfare, meanwhile, depends on the competitiveness of the industry.

3.1 Persistent Dominance – Innovation Effects

3.1.1 No Licensing

Consider first of all a simplified scenario in which no licensing is possible. If the leader wins the race, then the gaps are given by $g_L^{LN} = G + g$ and $g_F^{LN} = 0$. Hence

$$\pi_L^{LN} = \pi(G+g,0), \quad \pi_F^{LN} = \pi(0,G+g), \quad CS^{LN} = CS(G+g).$$

If the follower wins the race, then $g_L^{FN} = G$ and $g_F^{FN} = g$ and so

$$\pi_L^{FN} = \pi(G,g), \quad \pi_F^{FN} = \pi(g,G), \quad CS^{LN} = CS(G+g).$$

Notice that consumer surplus is the same whoever wins the race.

As discussed in Section 2, the incentive for each firm to innovate is dominated by its competitive threat – the difference in profits associated with winning and losing the race. We have

$$CT_L^N = \pi(G+g,0) - \pi(G,g), \quad CT_F^N = \pi(g,G) - \pi(0,G+g).$$

So if there is no licensing, the leader has a strictly greater incentive to innovate if and only if

(1)
$$\Sigma(G+g,0) > \Sigma(G,g).$$

This condition will always be satisfied in the context of homogeneous-product Cournot competition. Hence, for the general analysis presented in this section, we assume condition (1) holds and consequently the initial leader is the predicted winner of the race. In other words, we are in a persistent dominance setting.

3.1.2 Voluntary Licensing

We now allow the successful innovator to license its discovery to the rival firm in exchange for a fixed payment, thereby also increasing the rival's gap by an amount g. If the leader wins and licenses, then $g_L^{LV} = G + g$ and $g_F^{LV} = g$, and so

(2)
$$\pi_L^{LV} = \pi(G+g,g), \quad \pi_F^{LV} = \pi(g,G+g), \quad CS^{LN} = CS(G+2g).$$

Conditional on the leader being the first to discover, the minimum price that the leader would be willing to accept for the licence and the maximum price that the follower would be willing to pay for the licence are, respectively,

$$\underline{P}^{L} = \pi(G+g,0) - \pi(G+g,g) \text{ and } \overline{P}^{L} = \pi(g,G+g) - \pi(0,G+g).$$

So if the leader wins, voluntary licensing will take place if and only if

(3)
$$\Sigma(G+g,g) > \Sigma(G+g,0).$$

If the follower wins the race and licenses, then $g_L^{FV} = G + g$ and $g_F^{FV} = g$, and the values for the operating profits of each firm as well as consumer surplus are as above. That is, provided licensing takes place, operating profits and consumer surplus are the same, regardless of which firm makes the innovation. The minimum price that the follower would be willing to accept for the licence and the maximum price that the leader would be willing to pay are now, respectively,

$$\underline{P}^F = \pi(g,G) - \pi(g,G+g) \text{ and } \overline{P}^F = \pi(G+g,g) - \pi(G,g).$$

Therefore, if the follower wins, licensing will take place if and only if

(4)
$$\Sigma(G+g,g) > \Sigma(G,g)$$

Notice that, given the assumption that (1) holds, it follows from (3) and (4) that if the leader licenses the innovation then the follower certainly will; conversely, if the follower does not license the discovery, then neither will the leader. For competition authorities to want to compel firms to license, it must be the case that at least one of the firms would choose not to license voluntarily. So it certainly has to be the case that the leader does not license. Consequently, in what follows it will be assumed that

(5)
$$\Sigma(G+g,g) < \Sigma(G+g,0).$$

Nevertheless, in Appendix B we show that in a Cournot setting it is reasonable to assume that the follower will license, conditional on innovating.¹⁴ Hence it is assumed that (4) holds, which in combination with (5) implies that

(6)
$$\Sigma(G+g,0) > \Sigma(G+g,g) > \Sigma(G,g).$$

3.1.3 Voluntary Licensing Behaviour

Let us assume that, when the follower discovers first and licenses, the license payment is given by

$$P^{F} = \sigma \left[\pi(g, G) - \pi(g, G + g) \right] + (1 - \sigma) \left[\pi(G + g, g) - \pi(G, g) \right].$$

Here σ , $0 < \sigma < 1$, is the bargaining strength of the leader. Consequently, with voluntary licensing, the competitive threats of the leader and the follower are, respectively,

$$CT_L^V = CT_L^N - \sigma \left[\Sigma(G+g,g) - \Sigma(G,g) \right],$$

$$CT_F^V = CT_F^N + (1-\sigma) \left[\Sigma(G+g,g) - \Sigma(G,g) \right]$$

From (6) it follows that if firms can license, this will reduce the competitive threat of the leader but raise the competitive threat of the follower.¹⁵ It also follows that

(7)
$$CT_L^V - CT_F^V = \Sigma(G+g,0) - \Sigma(G+g,g) > 0,$$

so it still remains the case that the competitive threat of the leader is greater than that of the follower.

3.1.4 Compulsory Licensing

Under a policy of compulsory licensing, both firms know in advance of committing R&D resources that their discovery will have to be shared at FRAND prices if it is not shared voluntarily. As discussed in Section 2, we assume that such a FRAND licensing deal must be priced below the maximum willingness to pay of the purchaser. This implies that the FRAND licence price must satisfy

$$P^{FRAND} \leq \overline{P}^L = \pi(g, G+g) - \pi(0, G+g),$$

which we can write more conveniently as

(8)
$$P^{FRAND} = \phi \left[\pi(g, G+g) - \pi(0, G+g) \right],$$

with $0 \le \phi \le 1$. It is then possible to show that compulsory licensing will equalise the innovation incentives of the firms, thereby removing the prediction that the leader will win the innovation race.

 $^{^{14}\}mathrm{As}$ shown in Appendix B, a sufficient condition for this to occur is that $G \geq g.$

¹⁵This also replicates the result of Katz and Shapiro [1985] and others that voluntary licensing has an ambiguous effect on industry-wide innovation incentives, relative to no licensing. As in that paper, aggregate innovation incentives will rise if the bargaining strength of the licensor (here: the follower) is high, specifically if $1 - \sigma > \frac{1}{2}$.

Lemma 1. Under compulsory licensing, the competitive threat levels of the leader and follower are always identical: $CT_L^C = CT_F^C$.

Proof. It is straightforward to show that the competitive threats of the leader and the follower are now given by

$$\begin{split} CT_{L}^{C} &= CT_{F}^{C} = P^{FRAND} + P^{F} \\ &= \phi \left[\pi(g, G+g) - \pi(0, G+g) \right] \\ &+ \sigma \left[\Sigma(G, g) - \Sigma(G+g, g) \right] \\ &+ \left[\pi(G+g, g) - \pi(G, g) \right], \end{split}$$

which confirms the result.

The intuition for this result is clear. Regardless of whether a given firm wins or loses the race, flow profits will be constant. Since what matters in determining the competitive threat is the difference in profits associated with winning and losing the race, the incentives of the leader (to win so as to earn the FRAND fee and avoid paying under the voluntary licensing deal if the follower wins) are now exactly equal to those of the follower (to win so as to earn the voluntary licensing fee and avoid paying the FRAND price).

The next results summarises the innovation incentives of firms across voluntary and compulsory licensing regimes under persistent dominance.¹⁶

Lemma 2. The innovation incentives of the firms are ranked as follows: $CT_L^V > CT_F^V \ge CT_F^C = CT_L^C$.

Proof. Lemma 1 confirms the equality between competitive threats under compulsory licensing, while (7) confirms the rankings in the voluntary licensing regime. We can also see that compulsory licensing cannot increase the competitive threat of the follower, and decreases the competitive threat of the leader. By (8),

$$CT_F^C - CT_F^V = P^{FRAND} - \pi(g, G+g) + \pi(0, G+g) \le 0.$$

The inequality is strict if we have $\phi < 1$. Also,

$$CT_L^C - CT_L^V = P^{FRAND} - \pi(G+g,0) + \pi(G+g,g)$$

$$\leq \Sigma(G+g,g) - \Sigma(G+g,0)$$

$$< 0.$$

by (8) and (6).

This result confirms the cost side of the welfare trade-off discussed in the introduction: compulsory licensing can have harmful effects because it reduces industry-wide innovation incentives. On the basis of the above and Assumptions 1 and 2, we can also state the following result relating to the hazard rates, or innovation *probabilities*, of the firms.

¹⁶Since the main focus of the paper is the comparison between voluntary and compulsory licensing, we exclude for brevity the no-licensing regime from these comparisons.

Lemma 3. With regard to the hazard rates of the firms, the following ranking holds: $x^V > y^V \ge y^C = x^C$.

Before turning to the welfare implications of compulsory licensing, the following section discusses briefly the relevance of expectations and the "regulatory threat" for bargaining outcomes at the voluntary licensing stage. The results presented so far are robust to an alternative specification based on expectations.

3.1.5 Expectations View of Compulsory Licensing

So far we have not taken account of the fact that firms may anticipate the competition authority's intervention while bargaining over a voluntary licensing agreement. One may think that the mere threat of regulatory intervention might spur firms to agree voluntary deals that would not be agreed in the absence of such a threat. This is a central result in the literature on voluntary agreements in environmental regulation, for example.¹⁷ However, if we let θ , $0 \le \theta \le 1$, denote the (common) probability with which firms anticipate a compulsory licence being imposed in case no voluntary agreement is reached, it is possible to show that the licensing conditions (3) and (4) are unchanged when we allow for expectations. Intuitively, a higher probability of compulsory licensing increases the willingness of the innovator to sell the licence (implying a lower P) but also reduces the willingness of the non-innovator to pay for it (that is, \overline{P} also falls). Another interesting implication of this approach is that the imposition of compulsory licensing will now only affect innovation incentives if it alters the probability distribution reflected in θ (in which case a higher θ will reduce innovation incentives of both firms, as before). Since firms make R&D decisions on the basis of expected payoffs, if a compulsory licensing remedy does not change the probability with which firms anticipate compulsory licensing in future, it will not adversely affect innovation incentives.

3.2 Persistent Dominance – Welfare Effects

3.2.1 Consumer Surplus Standard

As a first step towards a full welfare analysis on the basis of a consumer surplus standard, we derive an expression for the expected present discounted value of consumer surplus, which accounts for R&D effects. Let v(x, y) denote this present discounted consumer surplus, given hazard rates x and y. We know that consumer surplus before an innovation occurs is given by $CS^0 = CS(G)$, while the consumer surplus following an innovation by firm j = L, F given licensing regime s = V, C is denoted

¹⁷See Manzini and Mariotti [2003], Arguedas [2005], Maxwell *et al.* [2000] and Segerson and Miceli [1998]. A notable difference in the barganing context analysed in those papers is that all firms lose out as a result of environmental regulation. In the compulsory licensing context, we have already seen that the non-innovator actually benefits when compulsory licensing is imposed.

by CS^{js} . It follows that the value to consumers must satisfy

$$rv(x^{s}, y^{s}) = x^{s} \left(\frac{CS^{Ls}}{r} - v(x^{s}, y^{s}) \right) + y^{s} \left(\frac{CS^{Fs}}{r} - v(x^{s}, y^{s}) \right) + CS^{0}.$$

Rearranging, we have

$$v(x^s, y^s) = \frac{x^s \frac{CS^{Ls}}{r} + y^s \frac{CS^{Fs}}{r} + CS^0}{x^s + y^s + r}$$

The necessary and sufficient condition for consumer surplus to be higher under compulsory licensing than under voluntary licensing is

$$v(x^C, y^C) > v(x^V, y^V).$$

This holds if and only if

(9)
$$\frac{2x^{C}x^{V}}{r} \left[CS(G+2g) - CS(G+g) \right] + CS(G) \left(x^{V} + y^{V} - 2x^{C} \right) \\ > x^{V}CS(G+g) - CS(G+2g) \left(2x^{C} - y^{V} \right).$$

The first term is positive and reflects the fact that, post-innovation, consumers will on average enjoy a higher level of surplus under compulsory licensing than under voluntary licensing, because the possibility that the leader will innovate and refuse to license is removed. The second term is positive because, as shown in Lemma 3, aggregate innovation rates are lower under compulsory licensing, which implies that consumers will enjoy the status quo profits for longer in expectation. Hence the inequality can only fail on account of the terms on the second line, the sign of which is ambiguous. On average, consumers will jump to a higher level of consumer surplus sooner under voluntary licensing since innovation rates are higher; on the other hand, the level of surplus that consumers will enjoy post-innovation under voluntary licensing is lower than that which they would enjoy post-innovation under compulsory licensing, due to the information sharing effect.

More generally, we can separate the terms in (9) into two types. Terms which are divided by r reflect discounted costs and benefits that accrue after the innovation – we refer to these as 'flow' terms. To differentiate these from terms which are not discounted, we will refer to the latter as 'stocks'. We can then rewrite (9) as

(10)
$$\frac{A}{r} + B > 0,$$

where A and B collect the flow and stock terms in (9), respectively. While it is true that A > 0, the sign of B is ambiguous. If B > 0, the above condition always holds. Moreover, since the risk free interest rate r weights the flow terms in this expression, even if B < 0, (10) will hold whenever $r < \frac{A}{-B}$ – that is, whenever the interest rate is below some critical value. The same reasoning holds in all other cases considered in this paper (that is, persistent dominance under a total welfare standard and action-reaction under both welfare standards). Whenever stock and flow terms have opposing signs, we know that there will be a critical value of the interest rate, call it \hat{r} , such that the flow terms will dominate the welfare effect whenever $r < \hat{r}$. We therefore simplify by assuming that r is sufficiently low, so that welfare effects are dominated by the flow terms.¹⁸

Assumption 3. The risk-free interest rate r is sufficiently low, so that the welfare effects of compulsory licensing are determined solely on the basis of the flow costs and benefits.

Of course, in the persistent dominance, consumer surplus case, this assumption then leads immediately to the following welfare result.

Proposition 1. Compulsory licensing increases consumer surplus, even when dynamic incentive effects are taken into account: $v(x^C, y^C) > v(x^V, y^V)$.

This result follows intuitively because compulsory licensing ensures that the most preferred consumer surplus outcome (that associated with information sharing) is achieved with certainty. Over an infinite horizon, this benefit dominates all the shortterm costs and benefits when interest rates are sufficiently low. We next consider the implications of compulsory licensing for total welfare.

3.2.2 Total Welfare Standard

Following similar derivations to those in Section 3.2.1, and using analogous notation, we can define the present discounted total welfare resulting from hazard rates x and y, given information sharing regime s = V, C, as

$$W(x^{s}, y^{s}) = \frac{x^{s} \left(\frac{\Sigma^{Ls}}{r} + \frac{CS^{Ls}}{r}\right) + y^{s} \left(\frac{\Sigma^{Fs}}{r} + \frac{CS^{Fs}}{r}\right) + \left(\Sigma^{0} + CS^{0}\right) - \left((x^{s})^{2} + (y^{s})^{2}\right)}{x^{s} + y^{s} + r}.$$

In terms of total welfare, compulsory licensing will be preferred to voluntary licensing if and only if

(11)
$$W(x^C, y^C) > W(x^V, y^V).$$

For the sake of clarity, on the basis of Assumption 3, we can focus our attention on the flow terms in the expression implied by (11), which then holds if and only if

$$2x^{C}x^{V}\left\{\left[\Sigma(G+g,g) - \Sigma(G+g,0)\right] + \left[CS(G+2g) - CS(G+g)\right]\right\} > 0.$$

Note that the welfare effect is not unambiguously positive. The first term in square brackets is the profit effect, which is negative by (6) (forcing the leader to license reduces industry profits). The second term is the consumer surplus effect and this

 $^{^{18}{\}rm This}$ also serves to justify Assumption 1, based on the inequality in footnote 14.

is clearly positive. While the net effect of these terms is ambiguous, the necessary and sufficient condition for compulsory licensing to increase total welfare is

(12)
$$[\Sigma(G+g,g) - \Sigma(G+g,0)] + [CS(G+2g) - CS(G+g)] > 0,$$

which leads to our next welfare result.

Proposition 2. With dynamic incentive effects taken into account, a policy of compulsory licensing is preferable to voluntary licensing in total welfare terms if and only if the positive consumer surplus effect outweighs the negative effect on firm profits.

As shown in Appendix B, in the homogeneous-product Cournot case, compulsory licensing will be total welfare enhancing if and only if the industry in question is sufficiently uncompetitive.¹⁹ Intuitively, in industries which are highly concentrated, the marginal consumer gain from promoting competition via information sharing will outweigh the marginal loss in terms of aggregate profits suffered by firms.

3.2.3 Foreclosure Standard

The foreclosure standard is motivated by a concern that successful innovation by the leader (as is predicted to occur under persistent dominance) might cause its lead over the follower to exceed the foreclosure margin, thereby forcing the follower to exit the market. It follows very naturally that compulsory licensing can safeguard the competitive process *per se* in such circumstances, since it guarantees that innovations made by either firm are shared.

Proposition 3. In the Cournot benchmark, compulsory licensing guarantees that both firms remain active in the market.

Proof. Appendix B.4.

There may be some refinements of this general result. If, for example, the leader is within one innovation of foreclosing the follower (that is, $\hat{g} - g < g_L - g_F < \hat{g}$) and the competition authority makes decisions with a delay, then it can be shown that the leader remains the predicted winner of the innovation race. This implies that there will be a period for which the follower exits the market, before the authority intervenes. The effectiveness of compulsory licensing in ensuring that competition persists then also depends on the follower's ability to meet any costs of waiting for the authority's intervention. Such refinements notwithstanding, the result that compulsory licensing protects competition *per se* appears simple and robust.

 $^{^{19}}$ It is well known that tournament models provide incentives for socially excessive investment in R&D (e.g. Beath *et al.* [1995]). It should be noted in this regard that our results are robust to the inclusion of spillovers (by which innovation incentives can be made arbitrarily small) and, as such, they are not driven by this average over-investment issue.

4 Action-Reaction

We now consider the effects of compulsory licensing on innovation rates and welfare in an action-reaction setting. Action-reaction requires that (i) the follower is the predicted winner of the race and (ii) successful innovation by the follower allows it to overtake the technological lead G of the incumbent. Assume, therefore, that if the follower innovates, its gap will increase by G + g, while if the leader innovates, its gap will increase by g. This implies that both firms are now racing to achieve a post-innovation gap of G + g.²⁰

4.1 Action-Reaction – Innovation Effects

4.1.1 No Licensing

We first need to determine the conditions under which action-reaction results. It is straightforward to show that the competitive threats of the firms are now given by

$$CT_L^N = \pi(G+g,0) - \pi(G,G+g)$$
 and $CT_F^N = \pi(G+g,G) - \pi(0,G+g)$,

and so the necessary and sufficient condition for the *follower* to be the predicted winner of the innovation race is

(13)
$$\Sigma(G, G+g) > \Sigma(G+g, 0).$$

Whether or not this condition holds will depend on the nature of the industry in question. Appendix B derives the relevant conditions for the homogeneous-product Cournot benchmark, which shows that action-reaction will occur in sufficiently uncompetitive industries. Since we are interested in investigating the implications of compulsory licensing in action-reaction industries, we assume that (13) is satisfied.

4.1.2 Voluntary Licensing

As before, conditional on successfully innovating, each firm decides whether or not to license its innovation to the rival firm. If the leader innovates and licenses, then $g_L^{LV} = G + g$ and $g_F^{LV} = g$, and so the operating profits and consumer surplus are as in the persistent dominance case, see (2). Hence the minimum price that the leader would accept in order to sell the licence and the maximum price that the follower would be willing to pay are unchanged, which in turn implies that the leader will again license if and only if

(14)
$$\Sigma(G+g,g) > \Sigma(G+g,0).$$

If the follower innovates and licenses, then $g_L^{FV} = 2G + g$ and $g_F^{FV} = G + g$. Operating profits and consumer surplus are now equal to

$$\pi_L^{FV} = \pi (2G + g, G + g), \ \pi_F^{FV} = \pi (G + g, 2G + g), \ CS^{FV} = CS(3G + 2g) > CS^{LV}.$$

²⁰It is also necessary to assume now that the incremental innovation g satisfies $0 \le g \le 1 - 2G$.

Hence the reservation prices are now given by

$$\underline{P}^F = \pi(G+g,G) - \pi(G+g,2G+g) \text{ and } \overline{P}^F = \pi(2G+g,G+g) - \pi(G,G+g),$$

and so licensing will take place if and only if

(15)
$$\Sigma(2G+g,G+g) > \Sigma(G,G+g).$$

In the context of homogeneous-product Cournot competition, it is shown in Appendix B that if the leader chooses to license, the follower certainly will, while if the follower chooses not to license, then neither will the leader. Moreover, in this context condition (13) guarantees that the follower *will* license, conditional on innovating. We therefore assume that (15) is satisfied (that is, the follower licenses) while (14) is not and instead the following holds

(16)
$$\Sigma(G+g,0) > \Sigma(G+g,g).$$

As in the persistent dominance case, this implies that only the follower will license its discovery voluntarily.

4.1.3 Voluntary Licensing Behaviour

We can write the license payment in the case where the follower innovates as

$$P^{F} = \sigma \left[\pi (G+g,G) - \pi (G+g,2G+g) \right] + (1-\sigma) \left[\pi (2G+g,G+g) - \pi (G,G+g) \right],$$

where σ , $0 < \sigma < 1$, is again the bargaining strength of the leader. The competitive threats are now

(17)
$$CT_{L}^{V} = CT_{L}^{N} - \sigma \left[\Sigma(2G+g,G+g) - \Sigma(G+g,G) \right], \\ CT_{F}^{V} = CT_{F}^{N} + (1-\sigma) \left[\Sigma(2G+g,G+g) - \Sigma(G+g,G) \right].$$

This shows that, despite the follower having been more likely to innovate in the first place, introducing voluntary licensing increases the competitive threat of the follower and decreases the competitive threat of the leader.²¹

4.1.4 Compulsory Licensing

Following the same definition of FRAND licensing given in Section 2, the FRAND licence fee must again satisfy

$$\begin{aligned} P^{FRAND} &= \phi \overline{P}^L \\ &= \phi \left[\pi(g, G+g) - \pi(0, G+g) \right], \end{aligned}$$

with $0 \le \phi \le 1$. Unlike before, however, the flow profits of a given firm associated with winning and losing the innovation race are not equal, which in turn implies that the innovation incentives are not equalised under compulsory licensing.

²¹Of course, this also implies that the follower will remain the predicted winner of the race. By (13) and (15) we have $CT_L^V - CT_F^V = \Sigma(G+g,0) - \Sigma(2G+g,G+g) < 0.$

Lemma 4. Under action-reaction, the follower remains the predicted winner of the innovation race when compulsory licensing is imposed: $CT_F^C > CT_L^C$.

Proof. We can write the competitive threats under compulsory licensing as

$$CT_L^C = \pi(G+g,g) - \pi(2G+g,G+g) + P^F + P^{FRAND},$$

$$CT_F^C = \pi(G+g,2G+g) - \pi(g,G+g) + P^F + P^{FRAND}.$$

Consequently, the follower will remain the predicted winner of the race if and only if $CT_F^C > CT_L^C$, which is to say

$$\Sigma(2G+g,G+g) > \Sigma(G+g,g).$$

Given (13), (15) and (16), this is always satisfied.

Moreover, we can see that compulsory licensing reduces the competitive threat of the leader and (weakly) reduces the competitive threat of the follower relative to voluntary licensing. By (16)

$$CT_L^C - CT_L^V \le \Sigma(G+g,g) - \Sigma(G+g,0) < 0.$$

Also, since $\phi \leq 1$,

$$CT_F^C - CT_F^V = (1 - \phi) \left[\pi (0, G + g) - \pi (g, G + g) \right] \le 0.$$

It is also straightforward to show that the leader's competitive threat always decreases by more than the follower's competitive threat. Therefore forcing the leader to license via a compulsory licence further strengthens the action-reaction properties of the race and, as such, the refusal by the leader to license voluntarily can be interpreted as an attempt to limit the extent of action-reaction.

We have shown above that (i) the follower is the predicted winner in the voluntary and compulsory licensing scenarios, that is $CT_L^C < CT_F^C$, $CT_L^V < CT_F^V$, and (ii) the competitive threats of both firms are lower under compulsory licensing than under voluntary licensing, that is $CT_L^C < CT_L^V$ and $CT_F^C \leq CT_F^V$. In general the difference $CT_F^C - CT_L^V$ may be either positive or negative, however.²² Hence we have the following result.

Lemma 5. With action-reaction, there is no clear ranking of competitive threat levels. Instead we have $CT_F^V \ge \max[CT_L^V, CT_F^C] > \min[CT_L^V, CT_F^C] > CT_L^C$.

In terms of hazard rates, this corresponds to the following result.

Lemma 6. With regard to firms' hazard rates, there is no clear ranking. Instead we have $y^V \ge \max[x^V, y^C] > \min[x^V, y^C] > x^C$.

²²Under persistent dominance we had $CT_L^V > CT_F^V \ge CT_F^C = CT_L^C$ (see Lemma 2).

Nonetheless, this still allows us to say that, overall, R&D spending will be higher under voluntary licensing than under compulsory licensing, in other words $x^V + y^V > x^C + y^C$, as in the case of persistent dominance. As in the analysis of the persistent dominance case, we now consider the welfare effects of compulsory licensing as judged both by a consumer surplus standard and a total welfare standard.²³

4.2 Action-Reaction – Welfare Effects

4.2.1 Consumer Surplus Standard

In order to analyse the consumer surplus implications of compulsory licensing, first consider the consumer surplus levels associated with the various outcomes of the innovation race. We have

- 1. $CS^F = CS(3G+2g)$ that which results if the follower innovates under either voluntary or compulsory licensing,
- 2. $CS^{LC} = CS(G + 2g)$ that which results if the leader innovates under compulsory licensing, and
- 3. $CS^{LV} = CS(G+g)$ that which results if the leader innovates under voluntary licensing.

Since CS' > 0 we know that $CS^F > CS^{LC} > CS^{LV}$. We can then write consumer surplus under compulsory licensing and voluntary licensing as

(18)
$$v(x^{C}, y^{C}) = \frac{x^{C} \frac{CS^{LC}}{r} + y^{C} \frac{CS^{F}}{r} + CS^{0}}{x^{C} + y^{C} + r}$$

and

(19)
$$v(x^V, y^V) = \frac{x^V \frac{CS^{LV}}{r} + y^V \frac{CS^F}{r} + CS^0}{x^V + y^V + r},$$

respectively. Note that, in contrast to the cases considered previously, the consumer surplus outcomes associated with compulsory licensing are not identical. That is, although it is preferable for the leader to license after innovating rather than not (since $CS^{LC} > CS^{LV}$), it is still *more* preferable for the follower to innovate since $CS^F > CS^{LC}$. In other words, moving to compulsory licensing no longer guarantees that the most preferred consumer surplus outcome will be attained. Relative to the persistent dominance case, this makes compulsory licensing relatively less attractive.

We know that compulsory licensing will be preferred to voluntary licensing if and only if

$$v(x^C, y^C) > v(x^V, y^V),$$

 $^{^{23}\}mathrm{We}$ do not consider the foreclosure standard here as the threat of the follower exiting the market is less acute.

which is now equivalent to

$$\frac{x^{C}x^{V}}{r} \left[CS^{LC} - CS^{LV} \right] + \frac{x^{V}y^{C}}{r} \left[CS^{F} - CS^{LV} \right] + CS^{0}(x^{V} + y^{V} - x^{C} - y^{C}) \\ > \frac{x^{C}y^{V}}{r} \left[CS^{F} - CS^{LC} \right] + \left[x^{V}CS^{LV} - x^{C}CS^{LC} \right] + CS^{F}(y^{V} - y^{C}).$$

The first two terms on the top line are positive and reflect the information sharing benefits that compulsory licensing brings relative to the case when the leader innovates under voluntary licensing (which occurs with probability x^V) and does not license. Relative to the corresponding expression in the persistent dominance case, the first term on the second line is new and reflects the fact that, even under compulsory licensing, the most preferred consumer surplus outcome is not guaranteed. There is a chance now that the leader will innovate under compulsory licensing giving consumer surplus CS^{LC} , when under voluntary licensing it would have been the follower that innovates giving consumer surplus $CS^F > CS^{LC}$ (this occurs with probability $x^C y^V$).

By Assumption 3, we know that the welfare effect will be determined on the basis of the flow terms. This allows us to simplify the above expression, which now holds if and only if

$$x^{C}x^{V}(CS^{LC} - CS^{LV}) + x^{V}y^{C}(CS^{F} - CS^{LV}) > x^{C}y^{V}(CS^{F} - CS^{LC}).$$

In contrast to the persistent dominance case, this need not always hold. Because compulsory licensing no longer guarantees that the most preferred outcome is attained, it is not unambiguously consumer surplus enhancing. On the basis of Lemma 6, however, we know that $y^V \ge \max[x^V, y^C] > \min[x^V, y^C] > x^C$, and so it seems reasonable to assume that $x^V y^C \approx x^C y^V$. If this is the case, the above condition will certainly be satisfied. Thus we have the following welfare result.

Proposition 4. Assume that $x^V y^C \approx x^C y^V$. Then, under action-reaction, compulsory licensing is unambiguously preferred to voluntary licensing in consumer surplus terms: $v(x^C, y^C) > v(x^V, y^V)$.

We next turn to the total welfare standard in an action-reaction setting.

4.2.2 Total Welfare Standard

Define the industry profit levels corresponding to the various race outcomes as

- 1. $\Sigma^F = \Sigma(2G+g, G+g)$ industry profits if the follower innovates under either voluntary or compulsory licensing,
- 2. $\Sigma^{LC} = \Sigma(G + g, g)$ industry profits if the leader innovates under compulsory licensing, and
- 3. $\Sigma^{LV} = \Sigma(G + g, 0)$ industry profits if the leader innovates under voluntary licensing.

We know from (13), (15) and (16) that $\Sigma^F > \Sigma^{LV} > \Sigma^{LC}$. The total discounted welfare corresponding to the compulsory and voluntary licensing regimes can then be written as

$$\begin{split} W(x^{C}, y^{C}) &= \frac{1}{x^{C} + y^{C} + r} \left\{ x^{C} \left(\frac{\Sigma^{LC}}{r} + \frac{CS^{LC}}{r} \right) + y^{C} \left(\frac{\Sigma^{F}}{r} + \frac{CS^{F}}{r} \right) \right. \\ &+ \left(\Sigma(G, 0) + CS^{0} \right) - \left((x^{C})^{2} + (y^{C})^{2} \right) \, \end{split}$$

and

$$\begin{split} W(x^V, y^V) &= \frac{1}{x^V + y^V + r} \left\{ x^V \left(\frac{\Sigma^{LV}}{r} + \frac{CS^{LV}}{r} \right) + y^V \left(\frac{\Sigma^F}{r} + \frac{CS^F}{r} \right) \\ &+ \left(\Sigma(G, 0) + CS^0 \right) - \left((x^V)^2 + (y^V)^2 \right) \right\}, \end{split}$$

respectively. The necessary and sufficient condition for compulsory licensing to be preferred to a voluntary licensing regime is $W(x^C, y^C) > W(x^V, y^V)$. Focusing our attention on the flow terms again, this condition is equivalent to

$$\begin{split} \left[\Sigma^{LC} + CS^{LC} \right] \left(x^C x^V + x^C y^V \right) + \left[\Sigma^F + CS^F \right] \left(x^V y^C - x^C y^V \right) \\ &> \left[\Sigma^{LV} + CS^{LV} \right] \left(x^C x^V + x^V y^C \right). \end{split}$$

If, on the basis of Lemma 6, we deem it reasonable to assume that $x^V y^C \approx x^C y^V$, this condition resembles the one derived in the persistent dominance case, and becomes

$$\left(\Sigma^{LC} - \Sigma^{LV}\right) + \left(CS^{LC} - CS^{LV}\right) > 0.$$

Proposition 5. Assume that $x^V y^C \approx x^C y^V$. Then, under action-reaction, compulsory licensing again induces a positive consumer surplus effect and a negative aggregate profit effect.

Which effect dominates will depend on the precise nature of the industry in question; but in the homogeneous-product Cournot setting, the consumer surplus effect will dominate in industries which are naturally less competitive.

5 Conclusion

This paper provides a framework to clarify the trade-off between static and dynamic efficiency that competition authorities face when considering a compulsory licensing remedy. Our welfare results suggest that, despite the fact that innovation incentives fall when compulsory licensing is imposed, such a policy nonetheless increases consumer surplus, and increases total welfare whenever the industry in question is sufficiently uncompetitive. It has also been shown that compulsory licensing can be an effective tool to preserve competition *per se* when there exists a threat of a dominant firm foreclosing its less efficient rival. Since competition authorities in

both Europe and the US claim to follow a consumer surplus standard, these results suggest that the infrequency with which compulsory licensing verdicts are observed in practice may be due to overestimation of the dynamic costs associated with such a policy (perhaps also under the influence of lobbying by dominant firms). Alternatively, competition authorities may in fact care about the welfare of firms (that is, follow a total welfare standard). In that case, a decision against compulsory licensing may reflect the view that the industry in question is sufficiently competitive. Extensions to this work should consider a setting of sequential innovations, and also explore other paradigms of innovation that are discussed in the literature (such as the quality ladder approach, which also fits more naturally into an explicitly sequential context).

Appendices

A A Zero Profit Incentive Representation

This section offers a justification for Assumptions 1 and 2 based on a simple approximation method, in which the profit incentive has been normalised to zero and the results can consequently be expressed solely in terms of competitive threats. Firms choose their R&D spending to maximise the present discounted value of expected profits, which, from the perspective of the leader having chosen hazard rate x when the follower chooses y, can be written as

$$V(x,y) = \frac{x\frac{\pi^W}{r} + y\frac{\pi^L}{r} + \pi^0 - x^2}{x + y + r}.$$

Multiplying the first order condition associated with this by r^2 and letting $X \equiv rx$ and $Y \equiv ry$ we can write it as

(20)
$$Y\left(\pi^{W} - \pi^{L}\right) + r^{2}\left(\pi^{W} - \pi^{0}\right) = X^{2} + 2XY + 2r^{2}X.$$

If we let $r \to 0$ and denote $\overline{X} \equiv \frac{\pi^W - \pi^L}{2}$ (that is, the competitive threat of the leader), (20) becomes

(21)
$$2\overline{X}Y = X^2 + 2XY \Rightarrow \overline{X} = \frac{X^2}{2Y} + X.$$

From this expression we can see that the best-response choice of X as $Y \to \infty$ is $X = \overline{X}$, (i.e. the competitive threat of the leader), whereas if Y = 0 then X = 0 (the profit incentive vanishes). Hence the optimal choice of hazard rate of the leader depends solely on the competitive threat. Similarly, for the follower, denoting its competitive threat by \overline{Y} , the first order condition yields

(22)
$$2\overline{Y}X = Y^2 + 2XY.$$

Adding X^2 to both sides of (22), rearranging for Y and substituting into (21), we have

(23)
$$X = 2(\overline{X} - X) \left[\sqrt{1 + \frac{2\overline{Y}}{X}} - 1 \right].$$

An equivalent expression holds from the perspective of the follower. Hence we can relate the optimal choice of hazard rates or, equivalently, R&D expenditure for either firm to just the magnitude of the competitive threats. Graphically, we can represent (23) as in Figure 1 below.



Figure 1: Equilibrium hazard rate for leader (X^e)

Here $\varphi(X) = X$ represents the left-hand side and

$$\psi(X) = 2(\overline{X} - X) \left[\sqrt{1 + \frac{2\overline{Y}}{X}} - 1 \right]$$

represents the right-hand side of (23). An increase in either \overline{X} or \overline{Y} will cause the graph of ψ to shift to the right, thereby increasing the equilibrium choice of R&D expenditure. This approximation therefore confirms Assumptions 1 and 2 in a context where the profit incentive has been normalised to zero.

B Cournot Benchmark

This section develops a homogeneous-product Cournot benchmark, which allows us to relate the various conditions on firm profits derived in the general analysis to two measures of industry competitiveness: the Herfindahl index in a general demand environment based on Février and Linnemer [2004], and demand elasticity in a linear demand example. Throughout, we consider firms' gaps in terms of their cost-reducing effect, so that the marginal cost for firm i is given by $c_i = 1 - g_i$, i = L, F.

B.1 General Demand Environment

Suppose that firms face an inverse demand function P(X), with P'(X) < 0 for all X > 0, where X is aggregate output. We restrict our attention to general convex demand functions.²⁴ However, to ensure the existence and uniqueness of the Cournot-Nash equilibrium, we need to assume that demand is not "too convex".²⁵ Suppose, therefore, that the elasticity of the slope of the inverse demand function $\Theta(X) = \frac{P''(X)X}{P'(X)}$ satisfies $-2 \leq \Theta(X) < 0$.

We can then recast the conditions on industry profits in terms of an exogenous shock w to the firms' marginal costs. This shock influences the firms' marginal costs via a sensitivity parameter γ_i , so that, post-shock, firm *i*'s marginal cost is given by $c_i + \gamma_i w$. Since we are interested in the incidence of a cost shock, rather than its precise magnitude, we can consider a shock of magnitude w = 1 without loss of generality. Février and Linnemer [2004] show that the necessary and sufficient condition for such a cost shock to increase the joint profits of the firms is

(24)
$$\frac{\overline{\gamma}}{2(3+\Theta^*)} \left(\Theta^*(H^*-1)-1\right) > cov(\gamma, s^*),$$

where Θ^* is the *ex ante* value of the elasticity defined above, $\overline{\gamma} = \frac{1}{2}(\gamma_L + \gamma_F)$ is the average shock sensitivity, s_i^* is the *ex ante* market share of firm i, $H^* = \sum (s_i^*)^2$ is the *ex ante* Herfindahl index, and $cov(\gamma, s^*) = \frac{1}{2} \sum (\gamma_i - \overline{\gamma})(s_i^* - 1/2)$ is the covariance between the shock sensitivities and market shares.

To illustrate, consider condition (1), $\Sigma(G+g,0) > \Sigma(G,g)$, which ensures a persistent dominance outcome. This corresponds to the effect of a shock with sensitivity parameters $\gamma_L = -g$, $\gamma_F = g$. Hence (24) now holds if and only if $cov(\gamma, s^*) < 0$, which is clearly satisfied. Hence (1) always holds in homogeneous-product Cournot.

B.2 Linear Demand Example

For the sake of this example, suppose that inverse demand is given by

$$P(X) = (1+\epsilon) - X,$$

 $^{^{24}\}mathrm{Examples}$ of commonly-used convex demand functions include negative exponential and constant elasticity demand.

²⁵Février and Linnemer [2004]

with $\epsilon > 1.^{26}$ Under the price-output combination $(1, \epsilon)$, i.e. that which prevails if price equals marginal cost under the previous industry standard,

$$\epsilon = -\frac{P'(X)X}{P(X)},$$

and hence ϵ measures the inverse elasticity of demand in the competitive equilibrium corresponding to the initial industry standard. As such, it gives a measure of the underlying 'uncompetitiveness' of the industry in which the firms are competing.²⁷ In a Cournot equilibrium, industry profits are symmetric and are given by

$$\Sigma(g_{\alpha}, g_{\beta}) = \frac{1}{9} \left[\left(\epsilon + 2g_{\alpha} - g_{\beta} \right)^2 + \left(\epsilon + 2g_{\beta} - g_{\alpha} \right)^2 \right].$$

B.3 Investigating the Conditions

We are now in a position to relate the various conditions on industry profits derived in the model to measures of industry competitiveness derived from the general demand environment (H^*) and linear demand example (ϵ). Consider first the **firms' licensing decisions under persistent dominance**. Condition (4) gives the necessary and sufficient condition for the follower to license, conditional on having innovated. In our general demand scenario, this corresponds to $\gamma_L = -g$ and $\gamma_F = 0$. Hence $cov(\gamma, s^*) < 0$ and (24) becomes

(25)
$$\frac{-g}{4(3+\Theta^*)}(\Theta^*(H^*-1)-1) > cov(\gamma, s^*).$$

This is more likely to hold, the higher is H^* – that is, the more uncompetitive is the industry. Conversely, the condition for the leader to license, equation (3), corresponds to $\gamma_L = 0$ and $\gamma_F = -g$. Therefore (24) becomes

(26)
$$\frac{-g}{4(3+\Theta^*)}(\Theta^*(H^*-1)-1) > cov(\gamma, s^*).$$

This is less likely to hold than (25), since now $cov(\gamma, s^*) > 0$. In terms of our linear demand example, the follower will license if and only if

$$2\epsilon > 3g - 10G,$$

and so again, this is more likely to hold, the higher is ϵ (the less competitive is the industry). A sufficient (but not necessary) condition for the follower to license is

²⁶This guarantees that both firms are active in equilibrium. We could alternatively assume $\epsilon > 0$, which allows for the possibility that the follower will be foreclosed.

²⁷Measuring elasticity at the competitive equilibrium avoids the Cellophane Fallacy. Note that $(1/\epsilon)$ also satisfies the axioms set out in Boone [2001] for measures of industry competitiveness, where we note with respect to condition (c) of Definition 2.2 (p. 712) that lower ϵ can shift the market structure from duopoly to monopoly (this requires $\epsilon < 1$ and $\epsilon < g_{\alpha} - 2g_{\beta}$). Hence if the leader is far enough ahead $(g_{\alpha} - 2g_{\beta})$ is sufficiently large), it can benefit as competition intensifies.

that $G \ge g$. The condition for the leader to choose to license, meanwhile, can be rewritten as

$$(27) 2\epsilon > 3g + 8G.$$

In terms of the **total welfare effect of compulsory licensing under per**sistent dominance, the necessary and sufficient condition for total welfare to be increased, equation (12), can be derived from Février and Linnemer [2004] as

$$\frac{-g}{4(3+\Theta^*)}(\Theta^*(H^*-1)-2) > cov(\gamma,s^*),$$

where again $cov(\gamma, s^*) > 0$. This is more likely to hold, the more concentrated is the industry (the higher is H^*). The same condition restated in terms of the linear demand example yields

$$(28) 8\epsilon > 3g + 14G,$$

and so again, the less competitive is the industry (the higher is ϵ), the more likely it is that the total welfare impact is positive.

Turning to the action-reaction scenario, the condition for the follower to be the predicted winner of the innovation race under action-reaction is given by (13). In terms of exogenous shocks, this is equivalent to $\gamma_L = g$, $\gamma_F = -(G+g)$. Hence $cov(\gamma, s^*) > 0$ and (24) becomes

(29)
$$\frac{-G}{4(3+\Theta^*)}(\Theta^*(H^*-1)-1) > cov(\gamma, s^*).$$

This is more likely to hold, the more concentrated is the industry. In the context of the linear demand example, (13) corresponds to

$$(30) 2\epsilon > 8g + 3G.$$

So action-reaction will result in industries which are naturally less competitive.

Finally, consider the **firms' licensing incentives under action-reaction**. The necessary and sufficient condition for the leader to license is as described in the persistent dominance case above. The condition for the follower to license voluntarily in the action-reaction setting, condition (15), corresponds in the general demand environment to $\gamma_L = -(G+g)$ and $\gamma_F = 0$, and so (24) becomes

(31)
$$\frac{-(G+g)}{4(3+\Theta^*)}(\Theta^*(H^*-1)-1) > cov(\gamma, s^*),$$

where $cov(\gamma, s^*) < 0$. It follows from (26) and (31) that if the leader licenses, the follower certainly will, while if the follower does not license, then neither will the leader. Note that now (29) guarantees that the follower will license. The same

results are obtained from the linear demand example. Here the condition for the follower to license is given by

$$2\epsilon > 3g - 7G,$$

while the condition for the leader to license is given in (27). Again, (30) – which ensures that action-reaction will occur – implies that the follower certainly will license.

B.4 Proof of Proposition 3 (Foreclosure Standard)

In the linear demand example, foreclosure will occur when $\epsilon < 1$ and $g_{\alpha} > \hat{g} \equiv \epsilon + 2g_{\beta}$. So if both firms are initially active, it must be true that

(32)
$$g_{\alpha} < \epsilon + 2g_{\beta}.$$

Since innovations are shared under compulsory licensing, the condition for the follower to remain active post-innovation is

$$g_{\alpha} + g < \epsilon + 2(g_{\beta} + g),$$

which is guaranteed to hold if (32) holds. Hence the leader cannot foreclose the follower if compulsory licensing is implemented. If $\epsilon > 1$ and the foreclosure margin is not defined, then the follower remains active irrespective of the licensing regime.

More generally, whenever the foreclosure margin \hat{g} is constant and not itself a function of the gaps g_{α} and g_{β} , the same result also holds.

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