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Duplicative research, mergers and innovation☆

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ABSTRACT

We show that in the model of Federico et al. (2017) horizontal mergers may actually spur innovation by preventing duplication of R&D efforts. Federico et al. do not notice this result because they presume that the merged firm spreads its R&D expenditure evenly across the research units of the merging firms—a strategy which is optimal, however, only if the probability of failure is log-convex in the RD effort. The possibility that mergers spur innovation is more likely, the greater is the value of innovations and the less rapidly diminishing are the returns to R&D.

1. Introduction

In an influential paper, Federico et al. (2017) analyse mergers in innovative industries. In their model, various firms invest in independent R&D projects, determining the probability that a pre-specified innovation is achieved. Federico et al. claim that in this framework mergers always reduce the R&D efforts of the merging firms (Proposition 1). We show that, in fact, their analysis requires one additional assumption which has gone unnoticed so far. The assumption is restrictive. When it fails, Federico et al.'s result may be reversed: mergers may increase innovation and consumer welfare.

The additional assumption serves to justify Federico et al.'s presumption that the merged firm spreads its total R&D expenditure evenly across its research units. Their hypotheses that firms are *ex-ante* symmetric, and that the returns to R&D are diminishing, are not sufficient for this. The probability of failure must be a log-convex function of R&D expenditure.

The reason for this is that in the model different research units may duplicate the same innovation. This creates convexities in the merged entity's profit function that tend to make asymmetry efficient. To overcome this tendency, the returns to R&D must diminish sufficiently rapidly. This is what log-convexity ensures.

But log-convexity may fail for well behaved R&D technologies. For example, constant elasticity functions entail log-convexity when R&D expenditure is low but log-concavity when it is high. In this latter case, the merged firm will operate different research units at different levels of intensity, even if all units are equally efficient. This can overturn the result that mergers impact innovative activity negatively.

2. The model

Federico et al. consider a radical innovation, such as for instance the invention of a new product. The private value of the innovation, i.e., the discounted value of the innovator's profits, is denoted by V. The social value is greater than V, so that more innovation is socially desirable.

To discover the new technology, various *ex-ante* symmetric firms invest in probabilistically independent R&D projects. A firm i that makes an R&D expenditure of R_i achieves the innovation with probability $x_i = F(R_i)$, with $F(0) = 0$. The "innovation production function" $F : [0, \bar{R}] \to [0, 1]$ is strictly increasing and concave, reflecting the presence of diminishing returns to R&D. It satisfies $F(\bar{R}) = 1$, where $\bar{R}$ may be either finite or infinite, and the Inada condition $F'(0) = \infty$. The inverse of F is the R&D cost function $R_i = C(x_i)$. It is strictly increasing and convex, with $C(0) = 0$ and $C'(0) = 0$.[1]

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1 Federico et al. assume also that $C'(1) = \infty$, which implies that $\bar{R}$ is infinite. We allow $\bar{R}$ to be finite to accommodate the iso-elastic example of Section 4. But this

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To get sharper results, we specialize Federico et al.'s model making conservative assumptions that maximize the likelihood that mergers have anti-competitive effects. Shapiro (2012) argues that of all mergers, those most likely to diminish innovative activity are the ones (p. 386)

> between the only two firms pursing a specific line of research to serve a particular need [...], absent a showing that the merger will increase appropriability or generate R&D synergies that will enhance the incentive or ability of the merged firm to innovate.

Accordingly, we

- consider two firms that merge into a monopoly;
- rule out synergies in research, assuming that the merger does not affect the innovation production function: all the merged entity can do is to reallocate R&D expenditure across the merging firms' research units efficiently;
- abstract from the possibility that the merger may increase appropriability, assuming that if both firms succeed, each gets a payoff of $\frac{1}{2}V$. The aggregate payoff from innovation is therefore always V both before and after the merger. For example, each innovator may have a 50% probability of getting the patent and becoming a monopolist in the product market. Alternatively, both innovators may be active but collude perfectly and split the market evenly.

3. Global results

Before the merger, each firm $i = 1, 2$ chooses R_i so as to maximize its expected profit

$$\begin{aligned}\pi_i &= x_i\left[(1-x_j)V + x_j\tfrac{1}{2}V\right] - R_i \\ &= F(R_i)\left[1-\tfrac{1}{2}F(R_j)\right]V - R_i. \end{aligned} \tag{1}$$

The profit function is concave in R_i, so the best response function is given by the first-order condition:

$$F'(R_i)\left[1-\tfrac{1}{2}F(R_j)\right]V = 1 \tag{2}$$

if the solution is interior; otherwise, we have a corner solution $R_i = \bar{R}$ which entails $x_i = 1$. The equilibrium is the fixed point of the best response functions. Like Federico et al., we focus on the symmetric equilibrium $R_1^* = R_2^* = R^*$.

The term inside square brackets in expressions (1) and (2) is lower than one and reflects the negative externality that each firm exerts on the other: when the rival also succeeds, the expected value of the innovation becomes $\frac{1}{2}V$ rather than V. When the two firms merge, they internalize the externality. The profit function becomes

$$\begin{aligned}\pi_M &= (x_1 + x_2 - x_1x_2)V - R_1 - R_2 \\ &= [F(R_1)+F(R_2)-F(R_1)F(R_2)]V - R_1 - R_2. \end{aligned} \tag{3}$$

The first-order conditions for a maximum are

$$F'(R_i)\left[1-F(R_j)\right]V = 1. \tag{4}$$

Federico et al. focus on the symmetric solution to the system of the first-order conditions (4), denoted by $R_1 = R_2 = R^{**}$. Under symmetry, the only way to internalize the externality is to reduce the R&D effort in both research units: $R^{**} < R^*$.

However, the symmetric solution R^{**} may be a saddle point rather than a maximum. The assumption of diminishing returns to R&D does not suffice to guarantee the optimality of R^{**}. The required condition is stated in Proposition 1.

is not crucial for our results. Any function F with a finite $\bar{R}$ can be approximated arbitrarily closely by one that belongs to the class considered by Federico et al. Thus, all the results of this paper would apply with minor changes to their exact framework.

Proposition 1. *The merged entity's optimal investment strategy is symmetric if and only if the function $1-F(R)$ is log-convex at $R = R^{**}$.*

Proof. The critical part of the second-order conditions is that the determinant of the Hessian matrix is positive. Simple calculations show that both this condition and the log-convexity of $1-F(R)$ are equivalent to

$$F''(R)\left[1-F(R)\right] + \left[F'(R)\right]^2 < 0$$

and are therefore equivalent to each other. ■

To get some intuitive insights, it is useful to think of the merged firm's optimization problem as composed of two stages: in the first stage, the merged entity chooses its aggregate R&D investment; in the second, it chooses how to split the total investment among the two research units efficiently. In the second stage, the objective is simply to maximize the overall probability of success $X = x_1 + x_2 - x_1x_2$. The term x_1x_2, which captures the risk of duplication, creates a convexity in the optimization problem.[2] For example, with constant returns to R&D a symmetric investment strategy is always inefficient: raising the R&D investment in one research unit and decreasing it by the same amount in the other always increases the probability of success. Diminishing returns to R&D counter this powerful tendency towards asymmetry, to some extent, but to overcome it fully, the returns to R&D must diminish sufficiently fast. This is what log-convexity ensures.

The condition in Proposition 1 is local. But varying V from 0 to ∞ makes R^{**} vary from 0 to $\bar{R}$. Thus, global log-convexity is necessary and sufficient to guarantee that a symmetric strategy is always optimal. Federico et al.'s analysis applies only under this additional condition.

But log-convexity may fail. If it does, the optimal solution may be asymmetric. The merged entity may decrease the R&D expenditure in one research unit to internalize the externality, reducing the risk of duplication x_1x_2, and increase the expenditure in the other to take advantage of the reduced risk. Consider for instance the case in which $1-F(R)$ is globally log-concave.

Proposition 2. *If $1-F(R)$ is globally log-concave, then the optimal strategy for the merged firm is $R_1 = \bar{R}$ and $R_2 = 0$ (or vice versa). The innovation is achieved with probability one.*

Proof. We first show that it is optimal to shut down one research unit. Let $X(R_1, R_2) = x_1 + x_2 - x_1x_2$ denote the overall probability of success. If $X(R_1+R_2, 0) \geq X(R_1, R_2)$, the claim follows immediately: any solution with positive R&D investments in both research units is dominated by one in which the same total R&D effort is concentrated in one unit.

To prove the claim, we must therefore show that if the failure function $1-F(R)$ is log-concave for any R, then $X(R_1+R_2, 0) \geq X(R_1, R_2)$. Since $\log[1-F(0)] = 0$, concavity of $\log[1-F(R)]$ implies

$$\log[1-F(R_1)] + \log[1-F(R_2)] \geq \log[1-F(R_1+R_2)]$$

or, equivalently

$$\log\{[1-F(R_1)][1-F(R_2)]\} \geq \log[1-F(R_1+R_2)].$$

But the log function is increasing, so this inequality implies

$$[1-F(R_1)][1-F(R_2)] \geq [1-F(R_1+R_2)].$$

This is equivalent to $1-X(R_1,R_2) \geq 1-X(R_1+R_2, 0)$ and hence to $X(R_1+R_2, 0) \geq X(R_1, R_2)$. This implies that it is optimal to shut down one research unit, setting, say, $R_2 = 0$.

[2] Salant and Shaffer (1998) also note, in a different framework, that non-concavities may naturally arise when firms coordinate their R&D activities.

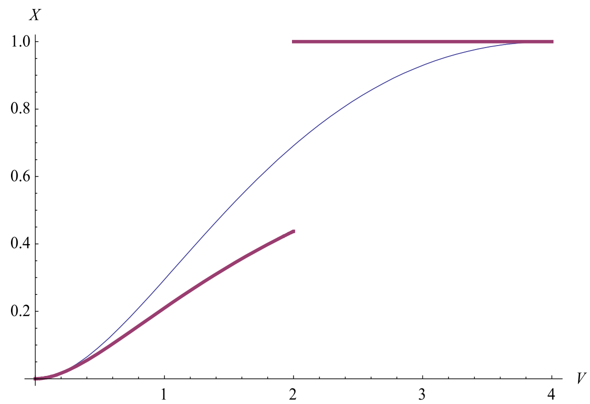

Fig. 1. The probability of success X before the merger (thin curve) and after the merger (thick curve) in the case $\theta = \frac{1}{2}$.

Having shown that $R_2 = 0$, it remains to show that $R_1 = \bar{R}$. This follows immediately from the first-order condition (4) and the Inada condition $F'(0) = \infty$. Taken together, these conditions imply that $R_2 = 0$ can be optimal only if $F(R_1) = 1$ and hence $R_1 = \bar{R}$. (Incidentally, this argument implies that with global log-concavity, $\bar{R}$ must be finite.) ■

Plainly, under global log-concavity the merger always weakly increases the probability of success. The increase is strict if $R^* < \bar{R}$, but even if $R^* = \bar{R}$ the merger is beneficial as it avoids wasteful duplication of efforts.

4. The iso-elastic case

Both global log-convexity and global log-concavity are restrictive assumptions. In general, the probability of failure may be log-convex for some values of R, log-concave for others.

Consider, for instance, the case of constant-elasticity innovation production functions

$$x_i = AR_i^{\theta} \tag{5}$$

where A is a scale parameter that with no further loss of generality is normalized to 1, so that $\bar{R} = 1$, and $0 < \theta < 1$. In this case, log-convexity holds when R_i is small ($R_i < (1-\theta)^{1/\theta}$), log-concavity when R_i is large ($R_i > (1-\theta)^{1/\theta}$).

The parameter θ is sometimes referred to as the "elasticity of supply" of inventions. It captures the extent to which the returns to R&D are diminishing. The empirical literature suggests that a reasonable range for this parameter is between a half and two thirds (Scotchmer, 2004; Denicolò, 2007). Luckily, for the cases $\theta = \frac{1}{2}$ and $\theta = \frac{2}{3}$ the model admits closed-form solutions that allow a direct comparison of the pre- and post-merger equilibrium.

When $\theta = \frac{1}{2}$, the pre-merger equilibrium is

$$R^* = \min\left[\frac{4V^2}{(4+V)^2}, \bar{R}\right]. \tag{6}$$

After the merger, the merged firm chooses symmetric R&D efforts

$$R^{**} = \frac{V^2}{(2+V)^2} \tag{7}$$

if the value of the innovation is small, i.e. $V < 2$. However, when $V \geq 2$ the optimum is given by an asymmetric corner solution:

$$R_1 = \bar{R}; \qquad R_2 = 0. \tag{8}$$

In this case, the merger reduces the R&D investment for small innovations but increases the investment for large innovations. This result is depicted in Fig. 1.

When $\theta = \frac{2}{3}$, the formulas for the pre- and post-merger equilibrium are too cumbersome to be reported here. The equilibrium is depicted in Fig. 2. Qualitatively, the pattern is the same as for the case $\theta = \frac{1}{2}$. The main difference is that an asymmetric interior solution now appears for intermediate values of V. Again, the merger stifles small innovations but spurs large ones.

In this simple model, monopoly always prevails in the product market. Therefore, the effect of the merger on consumer surplus has the same sign as the effect on innovation. When the value of innovation is large, mergers increase not only innovation but also social welfare.

5. Extensions

So far we have shown that mergers are more likely to spur innovation when innovations are large and the returns to R&D do not decrease too fast. But other factors may also be relevant, as discussed in Denicolò and Polo (2017). For example, mergers may affect appropriability. In our simple framework, this possibility can be captured by assuming that in case of duplication each firm obtains a fraction δ of V, with $\delta < \frac{1}{2}$. Denicolò and Polo (2017) show that this magnifies the impact of mergers on R&D but does not affect the sign. A more satisfactory analysis of the issue should perhaps model product market competition explicitly. But even so, the effects of mergers may remain uncertain, as a comparison of Federico et al. (2017a) and Bourreau and Jullien (2017) suggests.

Denicolò and Polo (2017) discuss also the consequences of relaxing the assumption of independent R&D projects. Mergers are more likely to increase innovation with positive correlation, less likely with negative correlation.

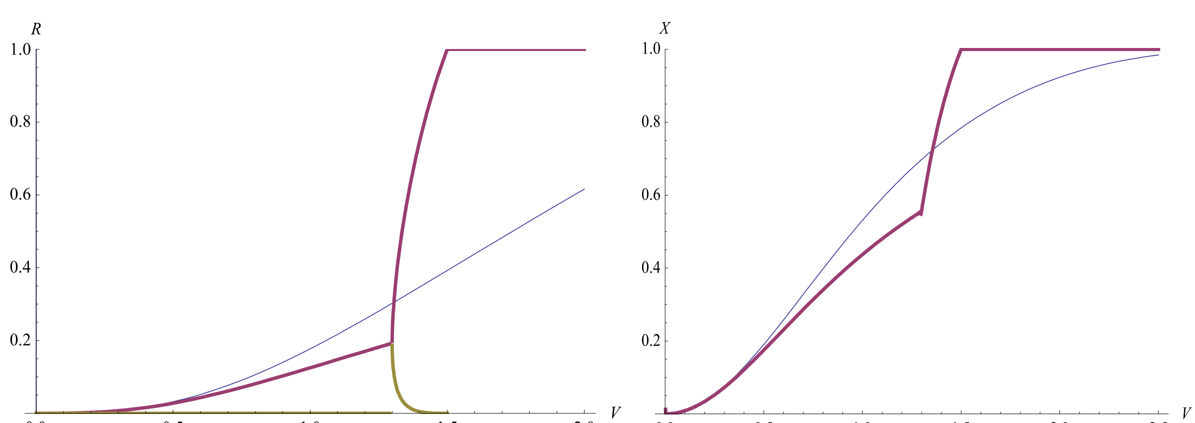

Fig. 2. The R&D investment in each research unit R_i (left panel) and the overall probability of success X (right panel) before and after the merger in the case $\theta = \frac{2}{3}$.

6. Conclusion

This paper shows that horizontal mergers do not necessarily stifle innovation. Thus, it casts doubts on the robustness of the "innovation theory of harm" articulated in Federico et al. (2017). The theory maintains that antitrust authorities may do well to block certain horizontal mergers that would pass the usual static efficiency tests, on the ground that these mergers hamper innovation. This theory has played a major role in the recent decision of the European Commission on the *Dow-DuPont* case. The impact of the theory on policy may not be limited to *Dow-DuPont*, however, as the Commission may apply the theory to other cases in the future, and other jurisdictions may follow the Commission's lead.

Our analysis suggests more caution in drawing general conclusions about the impact of mergers on innovation.

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