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ENDOGENOUS TIMING OF TECHNOLOGICAL CHOICES OF FLEXIBILITY IN A MIXED DUOPOLY

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Abstract

We study the adoption choices of flexible technologies to increase the range of products in a mixed duopoly. When firms' technological choices are simultaneous, the public ownership of a firm increases its incentives to adopt flexible technology and reduces those of its private competitor. The technologies used by the two firms can be reversed if the private firm chooses its technology before the public firm. If we make the timing of technological choices endogenous, it is simultaneous choices that are the equilibrium.

Keywords: Mixed duopoly, flexibility, technological choices, endogenous timing.

JEL Classification numbers: L32, L33, L13, O33.

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1 Introduction

In recent decades, many firms have replaced their traditional production lines with more robotic and flexible facilities. These flexible systems make it possible to adjust the pace of production more quickly to change in demand and to extend the range of goods that can be produced on the same production line.[1] In this study, we will focus on this second aspect.[2]

Röller and Tombak (1990) [RT continued] were among the first to develop a model designed to study the determinants of the adoption of flexible technology to extend the range of goods produced in a strategic context. Their study was extended by Röller and Tombak (1993), who increased the number of firms, Boyer, Jacques and Moreaux (2000), who analysed the impact of the possibilities of observing or not observing the technological choices of the competing firm before deciding on production levels, Jacques (2006 and 2021), who introduced the possibility for firms to enter into collusion agreements, and Bárcena-Ruiz and Olaizola (2008), who assumed that firm choices could be delegated to managers to whom they were able to strategically assign a different objective from profit maximization.

Previous studies have limited themselves to oligopolies consisting solely of private firms. Gil-Moltó and Poyago-Theotoky (2008) [GMPT thereafter] have pointed out that public firms, or firms in which public authorities hold significant holdings, are present in many industries,[3] especially in Europe and Asia. To analyse the impact of the public ownership of one of the firms on the adoption of flexible technologies, they have developed a model of choice of flexibility in a mixed duopoly, based on RT's model. As in most articles on mixed oligopolies, the authors assumed that the private firm was trying to maximise its profits while the public firm was trying to maximise the social surplus. The authors have therefore adopted as the objective of the public firm the social surplus function given by RT. Unfortunately, the latter contains an error due to the omission of a term in the consumer surplus.[4] The correction of this error significantly changes the results obtained by GMPT.

GMPT limited themselves to the study of technological choices when the firms make this choice simultaneously. However, the literature on mixed oligopolies has shown that the results obtained in this type of oligopoly often depend on the order of choice of the firms. In addition, the contributions which have endeavoured to make the timing of choices endogenous have led to rather contrasting results, but have shown the importance of not neglecting cases where the firm's choices are sequential. Sequential timings seem more likely when firms compete in quantities (Pal, 1998; Matsumura, 2003a; Jacques, 2004; Lu, 2006; Matsumura and Ogawa, 2010) and when they compete through R&D investments (Zikos, 2007). On the other hand, the chronology with simultaneous choices emerges when firms compete in price (Bárcena-Ruiz, 2007; Méndez-Naya, 2015). In other contexts, the timing of the equilibrium depends on the parameter values. This is the

[1] See Jacques (2003) for a survey.
[2] On the first aspect, see notably Boyer and Moreaux (1997) and Boyer, Jacques and Moreaux (2002).
[3] See GMPT for examples.
[4] See Castanheira de Moura and Jacques (2002).

case when firms compete in quantities with uncertainty about the level of demand that is resolved over time (Anam, Basher and Chiang, 2007) or when firms have to choose locations, and then start wage negotiations with their employees (Bárcena-Ruiz and Casado-Izaga, 2012). Finally, some models allow several types of timing as equilibria (Matsumura, 2003b) or may not admit pure strategies equilibrium (Zhang and Li, 2013). It therefore seems interesting to ask how the technological choices of firms are impacted by a change in chronology and to look for the timing that seems most likely if firms can influence it.

In this study, we extend the work of GMPT by analysing the technological choices of firms when they make their choice of flexibility sequentially and by determining the equilibrium timing when firms can decide when they make their choice of technology. This objective requires prior to resuming the case where the choices are simultaneous to eliminate the errors related to a mistake in the expression of the consumer surplus used by RT and GMPT.

In the mixed duopoly, when firms simultaneously choose their technology, they opt for flexible technology if the additional cost of the latter compared to a dedicated technology is low. Both firms adopt dedicated technologies if the additional cost of flexibility is high. If the additional cost of flexible technology lies between these two extremes, the equilibrium technological configuration is asymmetrical. The state-owned firm chooses flexible technology and the private company chooses a dedicated technology. The reverse technological configuration never appears in equilibrium. The area where the technological configuration is asymmetrical in the mixed duopoly totally encompasses the area where it is also asymmetrical in a duopoly composed of two private firms. The public firm therefore has more incentives than a private firm to adopt flexible technology and expand its product range. The intuition behind this result is that flexible technology makes competition more intense and increases consumer surplus. The public firm incorporates this beneficial impact for consumers, which leads it to choose flexibility for a wider range of parameter values than a private firm. In contrast, a private firm has less incentive to acquire flexible technology if it is opposed to a public firm than if it is confronted with another private firm. Indeed, taking into account the consumer surplus encourages a public firm to produce more than a private firm would. In reaction, its private competitor produces less than if it were confronted with a private firm. It therefore has less incentive to invest in expanding its product range.

If the public company selects its technology before the private company, the equilibrium technological configurations remain identical to those obtained in the game with simultaneous choices. The state-owned firm could use its leadership position to set up different configurations, but it never has any interest in doing so. On the other hand, if the role of leader is assigned to the private firm, the latter uses it, for certain parameter values, to implement an asymmetrical technological configuration in which it exploits a flexible technology while the public company uses a dedicated technology. The modification of the chronology of the game can therefore lead to an inversion of the tehnologies used by the two firms. When firms can decide when they will make the choice of their technology, everyone wants to make that choice as soon as possible to take on the leadership role. As a result, in equilibrium, the timing that imposes itself on equilibrium is

that in which the technological choices of firms are simultaneous.

When the ownership of firms has no impact on the equilibrium technological configuration, the social surplus is always higher in the mixed duopoly than in the private duopoly. It is therefore not in the interest of public authorities to privatise the public firm in these ranges of parameter values. On the other hand, when the privatization of the state-owned firm prompts its competitor to change technology in order to adopt flexible technology, this privatization sometimes increases the social surplus. When the private firm is the leader in the mixed duopoly, privatization of the public firm is desirable when the technological configuration is asymmetrical and the flexible technology is exploited by the private firm.

The model assumptions are presented in the next section. Section 3 analyses the case where the technological choices of the two firms are simultaneous. In section 4, we study the impact of a modification of the game's chronology on equilibrium technological configurations. In section 5, we make the timing of the game endogenous. In section 6, we determine the cases where privatization of the public firm increases the social surplus.

2 Model

We take the hypotheses of the model of Gil-Moltó and Poyago-Theotoky (2008) [GMPT in the following], which is itself based on that of Röller and Tombak (1990) [RT thereafter].

The model includes two firms (1 and 2), two goods (A and B) and two technologies: flexible (F) and dedicated (D). Flexible technology makes it possible to produce both goods. A dedicated technology makes it possible to produce only one. If firm 1 opts for dedicated technology, it produces good A while if firm 2 selects dedicated technology, it produces good B. The fixed cost of dedicated technology is equal to $F_D = 1$. Flexible technology fixed cost is higher, but lower than the cost of acquiring two dedicated technologies: $F_F = 1 + s$, with $s \in]0, 1[$.

Firms' variable costs are quadratic:[5]

$$C\left(q_i^A, q_i^B\right) = \left(q_i^A\right)^2 + \left(q_i^B\right)^2$$

The model is divided into two stages. In the first stage, the two firms choose their technology simultaneously. In the second case, they compete in quantities *à la* Cournot, having observed the technology chosen by the competing firm. In Section 4, the timeline of the game will be modified and cases where firms make their technological choices sequentially will be investigated.

RT only deal with the case where the two firms are private firms, whose objective is to maximise profit.

[5] This functional form is the one chosen by GMPT. RT assume that the marginal cost of firms is constant and identical for both technologies. However, with the latter hypothesis, the production of the private firm may be zero in a mixed duopoly if the public firm produces the same good at the same cost. To overcome this problem, GMPT introduced quadratic production costs.

GMPT also analyze the case where firm 1 is private while firm 2 is state-owned. In this mixed duopoly, the authors assume that the objective of the private firm is to maximise its profit while that assigned to the public firm is to maximise the welfare.

The demand for both goods comes from a representative consumer whose utility function is:

$$U\left(Q^A, Q^B\right) = a\left(Q^A + Q^B\right) - \frac{1}{2}\left[\left(Q^A\right)^2 + \left(Q^B\right)^2 + 2\lambda Q^A Q^B\right] + I$$

where I is the quantity consumed of a composite good. $\lambda \in [0,1]$ measures the degree of substitutability between the two goods.

From this utility function, we can deduce the inverse demand functions for goods A and B:

$$\begin{aligned} p^A\left(Q^A, Q^B\right) &= a - Q^A - \lambda Q^B \\ p^B\left(Q^A, Q^B\right) &= a - Q^B - \lambda Q^A \end{aligned}$$

as well as the consumer surplus:

$$CS\left(Q^A, Q^B\right) = U\left(Q^A, Q^B\right) - p^A Q^A - p^B Q^B = \frac{1}{2}\left[\left(Q^A\right)^2 + \left(Q^B\right)^2\right] + \lambda Q^A Q^B$$

RT argue (page 424) that the consumer surplus is equal to $\frac{1}{2}\left[\left(Q^A\right)^2 + \left(Q^B\right)^2\right]$, which is inconsistent with the presented utility function (page 420).[6] This error spread to GMPT, which used the RT formula.

The error also spread to the calculation of the total surplus, since the consumer surplus is one of the components of the social surplus:

$$TS = \pi_1 + \pi_2 + CS$$

However, maximization of this function is the objective assigned to the public firm in the mixed duopoly. The error in the consumer surplus formula therefore affects a significant portion of GMPT's results.[7]

3 Simultaneous technological choices

The case where technological choices are simultaneous has already been dealt with by GMPT, however when changing the formula of consumer surplus, many results change. The results presented in this section are therefore very different from those presented by GMPT.

We're looking for the perfect Nash equilibria of the model. We start by solving the quantities competition stage for each of the possible technological configurations before determining the technological choices of the firms.

[6] As mentioned by Castanheira de Moura and Jacques (2002) and Jacques (2003).
[7] In particular lemmas 4, 5 and 6 and propositions 2, 3 and 4.

3.1 Cournot competition

We first present the results obtained in a private duopoly before presenting those corresponding to a mixed duopoly.

3.1.1 Private duopoly

In the second stage, firms compete in quantities. Since the calculations are relatively standard, we limit ourselves, in the body of the text, to indicating the results obtained for each of the technological configurations (the first [second] letter, in the first column, indicates the technology of which the firm 1 [2] is equipped). The process that led to these results is a little more detailed in the appendix.

	Quantities	Prices	Payoffs
D,D	$q_1^A = \frac{1}{4+\lambda}a$ $q_2^A = 0$ $q_1^B = 0$ $q_2^B = \frac{1}{4+\lambda}a$	$p^A = \frac{3}{4+\lambda}a$ $p^B = \frac{3}{4+\lambda}a$	$\pi_1 = \frac{2}{(4+\lambda)^2}a^2 - F_D$ $\pi_2 = \frac{2}{(4+\lambda)^2}a^2 - F_D$ $CS = \frac{1+\lambda}{(4+\lambda)^2}a^2$ $TS = \frac{5+\lambda}{(4+\lambda)^2}a^2 - 2F_D$
F,F	$q_1^A = \frac{1}{5+3\lambda}a$ $q_2^A = \frac{1}{5+3\lambda}a$ $q_1^B = \frac{1}{5+3\lambda}a$ $q_2^B = \frac{1}{5+3\lambda}a$	$p^A = \frac{3+\lambda}{5+3\lambda}a$ $p^B = \frac{3+\lambda}{5+3\lambda}a$	$\pi_1 = \frac{2(2+\lambda)}{(5+3\lambda)^2}a^2 - F_F$ $\pi_2 = \frac{2(2+\lambda)}{(5+3\lambda)^2}a^2 - F_F$ $CS = \frac{4(1+\lambda)}{(5+3\lambda)^2}a^2$ $TS = \frac{4(3+2\lambda)}{(5+3\lambda)^2}a^2 - 2F_F$
F,D	$q_1^A = \frac{3(5-3\lambda)}{4(15-4\lambda^2)}a$ $q_2^A = 0$ $q_1^B = \frac{12-7\lambda+\lambda^2}{4(15-4\lambda^2)}a$ $q_2^B = \frac{6-\lambda-\lambda^2}{2(15-4\lambda^2)}a$	$p^A = \frac{45-15\lambda-7\lambda^2+\lambda^3}{4(15-4\lambda^2)}a$ $p^B = \frac{3\left(6-\lambda-\lambda^2\right)}{2(15-4\lambda^2)}a$	$\pi_1 = \frac{369-258\lambda-59\lambda^2+64\lambda^3-8\lambda^4}{8(15-4\lambda^2)^2}a^2 - F_F$ $\pi_2 = \frac{\left(6-\lambda-\lambda^2\right)^2}{2(15-4\lambda^2)^2}a^2 - F_D$ $CS = \frac{801+18\lambda-588\lambda^2+150\lambda^3+19\lambda^4}{32(15-4\lambda^2)^2}a^2$ $TS = \frac{2853-1206\lambda-1000\lambda^2+438\lambda^3+3\lambda^4}{32(15-4\lambda^2)^2}a^2 - F_D - F_F$
D,F	$q_1^A = \frac{6-\lambda-\lambda^2}{2(15-4\lambda^2)}a$ $q_2^A = \frac{12-7\lambda+\lambda^2}{4(15-4\lambda^2)}a$ $q_1^B = 0$ $q_2^B = \frac{3(5-3\lambda)}{4(15-4\lambda^2)}a$	$p^A = \frac{3\left(6-\lambda-\lambda^2\right)}{2(15-4\lambda^2)}a$ $p^B = \frac{45-15\lambda-7\lambda^2+\lambda^3}{4(15-4\lambda^2)}a$	$\pi_1 = \frac{\left(6-\lambda-\lambda^2\right)^2}{2(15-4\lambda^2)^2}a^2 - F_D$ $\pi_2 = \frac{369-258\lambda-59\lambda^2+64\lambda^3-8\lambda^4}{8(15-4\lambda^2)^2}a^2 - F_F$ $CS = \frac{801+18\lambda-588\lambda^2+150\lambda^3+19\lambda^4}{32(15-4\lambda^2)^2}a^2$ $TS = \frac{2853-1206\lambda-1000\lambda^2+438\lambda^3+3\lambda^4}{32(15-4\lambda^2)^2}a^2 - F_D - F_F$

3.1.2 Mixed duopoly

As for the private duopoly, we limit ourselves to giving the results and we refer to the appendix for the presentation of the details of the approach.

	Quantities	Prices	Payoffs
D,D	$q_1^A = \frac{3-\lambda}{12-\lambda^2}a$ $q_2^A = 0$ $q_1^B = 0$ $q_2^B = \frac{4-\lambda}{12-\lambda^2}a$	$p^A = \frac{9-3\lambda}{12-\lambda^2}a$ $p^B = \frac{8-2\lambda}{12-\lambda^2}a$	$\pi_1 = \frac{2(3-\lambda)^2}{(12-\lambda^2)^2}a^2 - F_D$ $\pi_2 = \frac{(4-\lambda)^2}{(12-\lambda^2)^2}a^2 - F_D$ $CS = \frac{25+10\lambda-12\lambda^2+2\lambda^3}{2(12-\lambda^2)^2}a^2$ $TS = \frac{93-30\lambda-6\lambda^2+2\lambda^3}{2(12-\lambda^2)^2}a^2 - 2F_D$
F,F	$q_1^A = \frac{2}{11+8\lambda+\lambda^2}a$ $q_2^A = \frac{3+\lambda}{11+8\lambda+\lambda^2}a$ $q_1^B = \frac{2}{11+8\lambda+\lambda^2}a$ $q_2^B = \frac{3+\lambda}{11+8\lambda+\lambda^2}a$	$p^A = \frac{2(3+\lambda)}{11+8\lambda+\lambda^2}\alpha$ $p^B = \frac{2(3+\lambda)}{11+8\lambda+\lambda^2}\alpha$	$\pi_1 = \frac{8(2+\lambda)}{(11+8\lambda+\lambda^2)^2}a^2 - F_F$ $\pi_2 = \frac{2(3+\lambda)^2}{(11+8\lambda+\lambda^2)^2}a^2 - F_F$ $CS = \frac{(1+\lambda)(5+\lambda)^2}{(11+8\lambda+\lambda^2)^2}a^2$ $TS = \frac{59+55\lambda+13\lambda^2+\lambda^3}{(11+8\lambda+\lambda^2)^2}a^2 - 2F_F$
F,D	$q_1^A = \frac{11-7\lambda}{4(11-3\lambda^2)}a$ $q_2^A = 0$ $q_1^B = \frac{8-5\lambda+\lambda^2}{4(11-3\lambda^2)}a$ $q_2^B = \frac{12-2\lambda-2\lambda^2}{4(11-3\lambda^2)}a$	$p^A = \frac{33-13\lambda-5\lambda^2+\lambda^3}{4(11-3\lambda^2)}a$ $p^B = \frac{6-\lambda-\lambda^2}{11-3\lambda^2}a$	$\pi_1 = \frac{370-292\lambda-42\lambda^2+72\lambda^3-12\lambda^4}{16(11-3\lambda^2)^2}a^2 - F_F$ $\pi_2 = \frac{\left(12-2\lambda-2\lambda^2\right)^2}{16(11-3\lambda^2)^2}a^2 - F_D$ $CS = \frac{521+6\lambda-376\lambda^2+90\lambda^3+15\lambda^4}{32(11-3\lambda^2)^2}a^2$ $TS = \frac{1549-674\lambda-548\lambda^2+250\lambda^3-\lambda^4}{32(11-3\lambda^2)^2}a^2 - F_F - F_D$
D,F	$q_1^A = \frac{2(3-\lambda)}{33-5\lambda^2}a$ $q_2^A = \frac{3(3-\lambda)}{33-5\lambda^2}a$ $q_1^B = 0$ $q_2^B = \frac{11-5\lambda}{33-5\lambda^2}a$	$p^A = \frac{6(3-\lambda)}{33-5\lambda^2}a$ $p^B = \frac{2(11-5\lambda)}{33-5\lambda^2}a$	$\pi_1 = \frac{8(3-\lambda)^2}{(33-5\lambda^2)^2}a^2 - F_D$ $\pi_2 = \frac{2\left(101-82\lambda+17\lambda^2\right)}{(33-5\lambda^2)^2}a^2 - F_F$ $CS = \frac{173+35\lambda-105\lambda^2+25\lambda^3}{(33-5\lambda^2)^2}a^2$ $TS = \frac{447-177\lambda-63\lambda^2+25\lambda^3}{(33-5\lambda^2)^2}a^2 - F_D - F_F$

3.2 Technological choices

After determining the quantities produced in each of the possible technological configurations, we analyze the technological choices of the firms. We start by determining the best response of one firm to the technology chosen by the other firm. We then determine the equilibria of the first stage of the game.

3.2.1 Best reply to the technology chosen by the competing firm

We start with the private duopoly and we continue with the analysis of the mixed duopoly.

Private duopoly: Flexible technology is the best reply to flexible technology if and only if:[8]

$$\pi_1(F,F) \geq \pi_1(D,F) \Leftrightarrow \frac{2(2+\lambda)}{(5+3\lambda)^2} - \frac{\left(6-\lambda-\lambda^2\right)^2}{2\left(15-4\lambda^2\right)^2} \geq \frac{s}{a^2}$$

Flexible technology is the best response to dedicated technology if and only if:

$$\pi_1(F,D) \geq \pi_1(D,D) \Leftrightarrow \frac{369-258\lambda-59\lambda^2+64\lambda^3-8\lambda^4}{8\left(15-4\lambda^2\right)^2} - \frac{2}{(4+\lambda)^2} \geq \frac{s}{a^2}$$

These conditions are more easily verified if the additional cost of flexible technology, s, is low and if the potential demand of consumers, a, is high.

[8] The first [second] letter appearing in the profit expressions is the technology chosen by firm 1 [2].

The expressions to the left of these inequalities are decreasing functions of λ. When λ increases, the two goods become closer substitutes. The amount that firms are willing to pay to acquire a technology to produce both goods logically decreases as λ increases.

It may be noted that, even if the two goods become perfect substitutes ($\lambda = 1$), the firms are still willing to pay a strictly positive sum to acquire the possibility of producing the second good. This is because the costs are quadratic. Thus, even if the two goods are identical, acquiring a second production line has a positive value, because it reduces the firm's variable production costs.

Mixed duopoly: The two firms having different objective functions, they have different better replies to the technological choice of the other firm. We start by studying the best replies from the private firm, then we determine those from the state-owned firm.

Best responses from private firm. Flexibility is the best response to the flexibility of the public firm if and only if:

$$\pi_1(F,F) \geq \pi_1(D,F) \Leftrightarrow \frac{8(2+\lambda)}{\left(11+8\lambda+\lambda^2\right)^2} - \frac{8(3-\lambda)^2}{\left(33-5\lambda^2\right)^2} \geq \frac{s}{a^2}$$

Adopting flexible technology is the best reply to the choice of a dedicated technology by the public company if and only if:

$$\pi_1(F,D) \geq \pi_1(D,D) \Leftrightarrow \frac{370-292\lambda-42\lambda^2+72\lambda^3-12\lambda^4}{16\left(11-3\lambda^2\right)^2} - \frac{2(3-\lambda)^2}{\left(12-\lambda^2\right)^2} \geq \frac{s}{a^2}$$

As in the previous case, the expressions to the left of the inequalities are decreasing functions of λ.

Best responses from the public firm. Flexibility is the best response to the adoption of flexible technology by the private firm if and only if:

$$TS(F,F) \geq TS(D,F) \Leftrightarrow \frac{59+55\lambda+13\lambda^2+\lambda^3}{\left(11+8\lambda+\lambda^2\right)^2} - \frac{1549-674\lambda-548\lambda^2+250\lambda^3-\lambda^4}{32\left(11-3\lambda^2\right)^2} \geq \frac{s}{a^2}$$

Opting for flexible technology is the best reply to the choice of a dedicated technology by the private company if and only if:

$$TS(F,D) \geq TS(D,D) \Leftrightarrow \frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2} - \frac{93-30\lambda-6\lambda^2+2\lambda^3}{2\left(12-\lambda^2\right)^2} \geq \frac{s}{a^2}$$

The left members of inequalities are decreasing functions of λ. Like the private firm, the public firm is willing to invest less to acquire flexible technology if the two goods are closer substitutes. GMPT gets a different result for the second condition. They find that this condition is a nonmonotonous function of λ. They get a U-shape. Which seems pretty counterintuitive.

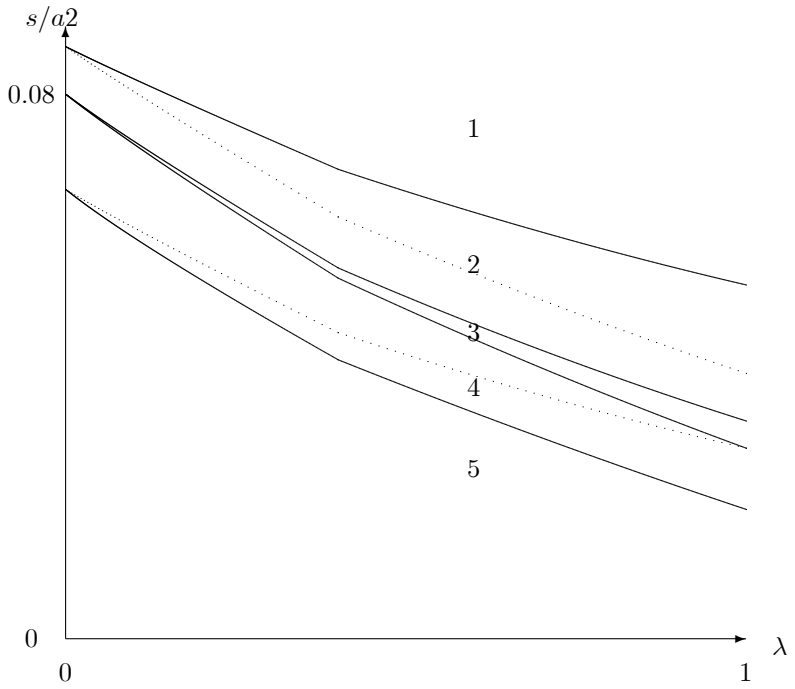
3.2.2 Technological equilibria

We can now determine the equilibria of the first stage of the game.

Graphic representation: We start by showing on the same graph, the six functions of the previous technological best replies. Like Boyer, Jacques and Moreaux (2000), we chose to put $\frac{s}{a^2}$ on the y-axis rather than s. This avoids having to arbitrarily set a value for one of the parameters and allows us to visualize all the results on one graph.

The highest border is the best response from the public firm to D. Moving down, we then have (in dotted lines) the best response from the public firm to F. The next two boundaries correspond to those of a private duopoly. The best reply to D is above the best answer to F. Finally come the best replies of the private firm to the technological choice of the public firm in a mixed duopoly. The highest (dotted) is the best response to D; the lowest is the best response to F. The following figure is thus obtained.

Figure 1: Technological equilibria with simultaneous choices



The table below shows the technological equilibrium obtained in each of the five relevant areas of the figure for each of the two types of duopoly.

	Private duopoly	Mixed duopoly
1	(D,D)	(D,D)
2	(D,D)	(D,F)
3	(D,F) or (F,D)	(D,F)
4	(F,F)	(D,F)
5	(F,F)	(F,F)

We can emphasize that the different borders do not cut on this figure. The results obtained are therefore very different from those of GMPT where several intersections of the best technological responses appear.[9]

Private duopoly: The situation where the two firms are private will serve as a point of comparison to understand the impact of the public ownership of one of the firms. It is also of interest in itself. Indeed, this situation has already been studied by RT, but for the case where the firms' cost functions are linear. It is interesting to see if the results are robust to a change in the cost function.[10]

The two best reply functions that correspond to those of a private firm versus another private firm are those that delimit zone 3. The most notable result is that the border corresponding to the best response to a flexible technology is above the one corresponding to the best response to a dedicated technology. The position of these two frontiers is therefore reversed in relation to that obtained with a constant marginal cost (Kim, Röller and Tombak, 1992). The results therefore diverge for the intermediate values of s/a^2. RT get a flexible trap. This is an area where there are two equilibria in pure strategies, (D, D) and (F, F), and in which firms prefer equilibrium (D, D). There is therefore no area where the two firms make different technological choices in a pure strategies equilibrium.[11] With quadratic costs, there is a range of values of s/a^2 for which firms adopt different technologies.

Outside the previous zone, we find the RT fund trends. Firms adopt F technology when its fixed cost is low relative to the size of the market and when the differentiation between the two goods is strong. Firms adopt tehnology D in opposite cases.

Mixed duopoly: If the additional fixed cost of flexibility is very low, both firms opt for technology F (zone 5). If the additional cost of flexibility is very high, both firms choose a dedicated technology (zone 1). Between these two cases (zones 2 to 4), firms adopt different technologies. The public firm invests in flexible technology and therefore produces both goods. The private company installs a dedicated technology and is limited to the production of good B.

[9] See their figures 1 and 2.

[10] The results reported by GMPT are different from those obtained in this study. GMPT providing very little detail on the private duopoly, it is difficult to understand the reason for these differences.

[11] Firms may adopt different technologies in some variants of the RT model. This is the case when the number of firms exceeds two (Röller and Tombak, 1993), if firms cannot observe the technological choice of their competitor before deciding on the quantities to be produced (Boyer, Jacques and Moreaux, 2000), if choices are delegated to managers who are strategically assigned a different goal from profit maximization (Bárcena-Ruiz and Olaizola, 2008), if the additional cost of flexible technology is not the same for both firms (He, Ding and Hua, 2012) or if firms can enter into extensive collusion agreements on technological choices (Jacques, 2021).

The incentives of the public firm to invest in flexible technology are always higher than those of the private firm. This result is due to the fact that the state-owned firm takes into account the consumers surplus. Adoption of F technology increases competition between firms and benefits consumers.[12] The public firm also takes into account that if it adopts technology F, the private firm will reduce its production levels and will suffer a reduction in its profit. But the positive effect on the consumers surplus dominates the negative effect on the profit of the private firm. The state-owned firm therefore selects F technology more often than the private firm. There is an area where equilibrium is (D, F), but none where equilibrium is (F, D).[13]

It can also be emphasized that there is no zone of parameter values with multiple equilibria.

Comparison: A comparison of the equilibria obtained in the mixed duopoly and in the private duopoly gives clear results. The area where (F, F) is an equilibrium is wider in a private duopoly than in a mixed duopoly. The area where (D, D) is an equilibrium is also wider in the private duopoly than in the mixed duopoly. The area where firms choose different technologies in the mixed duopoly totally encompasses the area where firms opt for opposite technologies in the private duopoly.

Proposition 1 *The shift from a private to a mixed duopoly increases the public firm's incentives to invest in flexible technology and reduces the private firm's incentives to choose flexible technology.*

A public firm takes into account the beneficial effect of technology F on the surplus of consumers. This increases its incentives to invest in flexible technology. A private firm confronted with a public firm anticipates that its production levels will be lower than if it were opposed to another private firm, which reduces its incentives to invest in more expensive technology to increase its product range.

4 Sequential choices

In this section, we will investigate whether the order in which firms choose their technology has an impact on the technological equilibrium configuration. So we change the game's timeline, which now includes three stages. In the first, the leading firm chooses its technology. In the second, the other firm observes the technology adopted by the leading firm, then decides whether to acquire the F or D technology. In the third stage, the two firms compete in quantities. In this section, the leadership role is assigned to either firm exogenously. We'll make the timing endogenous in the next section.

[12] RT and Castanheira de Moura and Jacques (2002) have shown this in the case where the marginal cost of firms is constant in a private duopoly.

[13] Contrary to the results presented by GMPT.

4.1 The public firm is the leader

We start with the case where the leadership role is assigned to the public firm. If the equilibrium of the simultaneous play is (D, D) or (F, F), the modification of the chronology of the play has no impact on the equilibrium configuration.

Nor does it have any in the area above the best response of the private firm to D and below the best response of the public firm to D. This area covers zones 2 and 3, as well as the top of zone 4. In this area, the private firm acquires a technology D regardless of the technological choice of the public firm. The public company therefore chooses a technology F. The equilibrium configuration is therefore (D, F) as in the simultaneous game.

The bottom of zone 4, more precisely the area between the two best response functions of the private firm to the technological choice of the public firm, is more interesting. In this area, the equilibrium of the simultaneous play is (D, F). But, in the sequential game, if the public firm modifies its technology and opts for D, the private firm will, in return, change its technology and select F. The public firm therefore has the choice between configurations (D, F) and (F, D). She prefers the second if and only if:

$$TS(F, D) \geq TS(D, F) \Leftrightarrow \frac{\left(1549 - 674\lambda - 548\lambda^2 + 250\lambda^3 - \lambda^4\right)\left(33 - 5\lambda^2\right)^2}{32\left(11 - 3\lambda^2\right)^2\left(447 - 177\lambda - 63\lambda^2 + 25\lambda^3\right)} \geq 1$$

The ratio to the right of the inequality is always less than 1. The state-owned firm therefore always prefers (D, F) to (F, D). The equilibria obtained, in the mixed duopoly, when the public firm is leader are identical to the equilibrium of the game where the technological choices are simultaneous.

4.2 The private firm is the leader

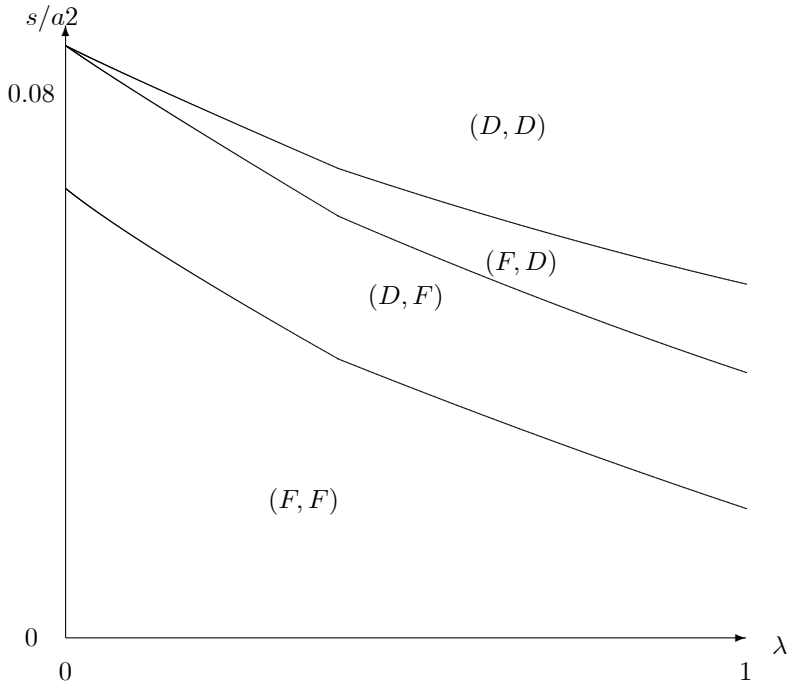
It is now assumed that the private firm is the first to make its technological choice. This does not change the technological configuration if the equilibrium of the simultaneous play is (D, D) or (F, F). A change can only occur in the area where (D, F) is the equilibrium of the simultaneous play. Below the best response of the public firm to F, the private firm cannot influence the technological choice of the public firm. For the public firm acquiring a flexible strategy is a dominant strategy. The private firm can therefore do no better than to opt for D. We thus obtain the same equilibrium (D, F) as in the simultaneous game. On the other hand, in the area between the two best response functions of the public firm (the top of zone 2), the private firm can impose the configuration (F, D) by adopting the F technology before the public firm chooses its technology. In this zone, the private firm therefore has the choice between configurations (F, D) and (D, F). It selects the first if and only if:

$$\pi_1(F, D) \geq \pi_1(D, F) \Leftrightarrow \frac{370 - 292\lambda - 42\lambda^2 + 72\lambda^3 - 12\lambda^4}{16\left(11 - 3\lambda^2\right)^2} - \frac{8(3 - \lambda)^2}{\left(33 - 5\lambda^2\right)^2} \geq \frac{s}{a^2}$$

This border is located above the border where the best response of the public firm to a dedicated technology is a flexible technology. The private firm chooses F and the public firm reacts by selecting D.

In short, when the private firm is a leader, we obtain the following technological equilibria.

Figure 2: Technological equilibria when the private firm is the leader



When the private firm is the leader, there is an area where (F, D) is an equilibrium in a mixed duopoly. It is recalled that this configuration never appears, in the mixed duopoly, when the technological choices of the firms are simultaneous. Changing the game's chronology can therefore reverse the technological choices of firms when the private firm becomes a leader. This reversal leads to a reduction in the consumer surplus and the social welfare.[14]

In this area, the technological equilibrium configuration in a private duopoly is (D, D). It is therefore possible that the mutation from a private duopoly to a mixed duopoly will lead to a transition to the flexible technology of the firm that remains private, but this can only happen if this firm makes its technological choice before the public firm.

Proposition 2 *A private firm may choose a more flexible technology if it is confronted with a public firm than if it is opposed to a private firm if (and only if) it chooses its technology before its competitor.*

[14] We saw above that we always have: $TS(F, D) \geq TS(D, F)$.

5 Endogenous timing

In the previous sections, the timing of the technological choices was exogenous. In this section, we will make it endogenous by considering the game with observable delay proposed by Hamilton and Slutsky (1990).

In this variant, the game breaks down into four stages. In the first stage, each firm simultaneously announces whether it will choose the technology in the second or third stage. This announcement is engaging. In steps 2 and 3, firms choose their technology according to the timing on which they are committed. In the fourth stage, firms compete in quantities.

We have seen above that the technological configuration is independent of the order of the choices of the firms, with the exception of the zone where the equilibrium is (F, D) if the private firm is the leader and (D, F) in the other possible timings. In this area, the private firm prefers to be leader to play at the same time as the public firm. Moreover, she is indifferent between playing at the same time as the public firm and being a follower. For the private firm, announcing that it will choose its technology in stage 2 is a weakly dominant strategy. Similarly, making its technological choice in stage 2 is a weakly dominant strategy for the state-owned firm. The latter prefers to play at the same time as the private firm rather than to be a follower and it is indifferent between being a leader and playing at the same time as the private firm.

If we eliminate the weakly dominated strategies, we get the following result:

Proposition 3 *In a mixed duopoly, the two firms want to adopt their technology as soon as possible. Simultaneous timing is the one that emerges at equilibrium when the timing is endogenous.*

If we keep the weakly dominated strategies, the timing where the public firm is the leader and the private firm plays second is also a perfect Nash equilibrium of the game.

The technological configuration (F, D) is never an equilibrium in the game with endogenous timing.

6 Impact of privatisation on the welfare

In this section, we compare the social surpluses obtained in a mixed duopoly and in a private duopoly in order to determine whether the privatization of the public firm can increase the social surplus. We first analyse the case where technological choices are simultaneous, then the case where they are sequential.

6.1 Simultaneous choices

In zones 1, 3 and 5 (in Figure 1), privatization of the public firm does not change the technological choices of firms. However, it changes the quantities produced by each of the firms. In these areas, privatization leads

to a reduction in the social surplus.[15]

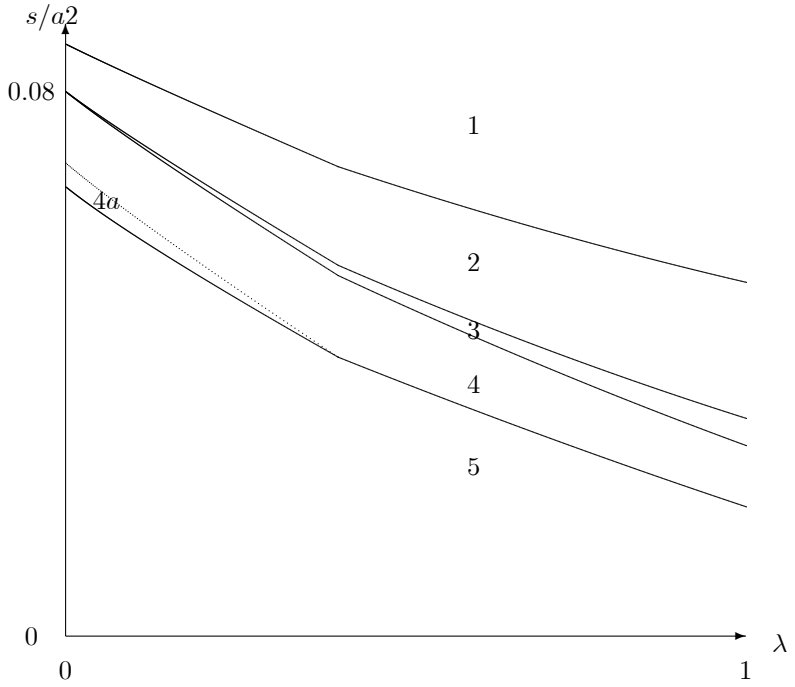
In zone 2, the privatization of the public firm leads to a change in the technological equilibrium configuration, from (D, F) to (D, D). Comparing the social surpluses in both situations,[16] we observe that privatization decreases the social surplus.

In zone 4, the privatization of the state-owned firm is also followed by a change in the technological configuration. The direction of this change, however, is opposed to that of zone 2. In zone 4, privatization results in increased flexibility for industry. The equilibrium technology configuration changes from (D, F) to (F, F). The private firm expands its product range and increases its production if the public firm is privatized. Privatization increases the social surplus if and only if:

$$\begin{aligned} \frac{4(3+2\lambda)}{(5+3\lambda)^2}a^2 - 2F_F &\geq \frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2}a^2 - F_D - F_F \\ &\Leftrightarrow \frac{4(3+2\lambda)}{(5+3\lambda)^2} - \frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2} \geq \frac{s}{a^2} \end{aligned}$$

This condition is checked for certain parameter values. The area where this occurs (zone 4a) can be viewed by representing the previous condition in Figure 1.

Figure 3: Area where privatization is optimal when choices are made simultaneously



In summary, privatization of the public firm can only increase the social surplus if (1) the initial technolog-

[15] See Appendix for details of the calculations of social surplus comparisons.
[16] See Appendix.

ical configuration is (D, F), (2) privatization induces the competing firm to adopt a more flexible technology and (3) the differentiation between the two goods is relatively strong.

Proposition 4 *Privatization of the public firm may increase the social surplus if it induces the private firm to adopt a more flexible technology.*

6.2 Sequential choices

If the equilibrium technological configuration when the choices are sequential is identical to that obtained when the choices are simultaneous, the previous results will continue to apply. In particular, in the area where privatization is optimal when technological choices are simultaneous, privatization remains socially desirable when technological choices are sequential.

It remains to analyse the consequences of privatization in the area where the equilibrium is (F, D) in the mixed duopoly when the private firm is the leader. This is, in fact, the only area where a sequential equilibrium is different from the equilibrium of the simultaneous game. In this area, when the private firm is the leader, privatisation leads to a change from (F, D) to (D, D). Privatization leads to a reduction in the private firm's product range. This contraction has a negative effect on the consumer surplus. However, it is accompanied by a reduction in the firm's fixed costs, which are relatively high in this area. This second effect can be beneficial for the social surplus. In this area, privatization increases the social surplus if and only if:

$$\frac{5+\lambda}{(4+\lambda)^2}a^2 - 2F_D \geq \frac{1549 - 674\lambda - 548\lambda^2 + 250\lambda^3 - \lambda^4}{32\left(11-3\lambda^2\right)^2}a^2 - F_F - F_D$$

$$\Leftrightarrow \frac{s}{a^2} \geq \frac{1549 - 674\lambda - 548\lambda^2 + 250\lambda^3 - \lambda^4}{32\left(11-3\lambda^2\right)^2} - \frac{5+\lambda}{(4+\lambda)^2}$$

This boundary passes below the frontier delineating the area where (F, D) is the equilibrium. The condition is therefore checked throughout the area where (F, D) is chosen in the mixed duopoly when the private firm is the leader. In this area, it is optimal to privatize the state-owned firm.

Proposition 5 *When the private firm is the leader, the privatization of the public firm is desirable throughout the area where the technological configuration is* (F, D).

7 Conclusion

In this study, we looked at the impact of firm ownership, as well as the timing of choices on decisions to adopt a flexible or dedicated technology in a duopoly.

In a mixed duopoly, the two firms equip themselves with flexible technology when the additional cost of this technology (s) is small relative to the size of the potential demand (measured by a^2). In contrast, if

the ratio s/a^2 is high, both firms acquire dedicated technologies. For the intermediate values of s/a^2, the technological equilibrium configuration is asymmetrical. The public company chooses flexible technology and the private company chooses dedicated technology. The reverse technological configuration never appears in equilibrium. In a private duopoly, we find the same classification of the different possible technological configurations according to s/a^2. However, the boundaries of the different zones are different. In particular, the area where the configuration is asymmetric in the private duopoly is totally included in the area where the technological choices of the two firms are different in the mixed duopoly. It therefore appears that the public ownership of one of the firms increases its incentives to equip itself with flexible technology and reduces that of its private competitor to acquire flexible technology.

When the private firm can choose its technology before the public firm, a new technological configuration emerges in equilibrium for certain parameter values. There is a zone of parameter values in which the private firm operates a flexible production line while the public firm limits its investments to the acquisition of a line dedicated to the production of a single product. The range of products offered by the private firm is then wider than that of the state-owned firm. In this area, we observe a reversal of the technologies of firms in relation to the game where the technological choices are simultaneous. This reversal allows the private firm to increase its profits, but it results in a decrease in the consumer surplus and the social surplus.

When the order of technological choices has an impact on the equilibrium technological configuration, the private firm prefers the situation in which it is the leader while the public firm prefers the other timings. Each of the firms wishes to commit to the earliest date to decide on its technological choice. The endogenous timing of equilibrium is one where technological choices are simultaneous.

The privatization of the state-owned firm never increases the social surplus, if this privatization does not change the technological choice of the private firm. On the other hand, privatization may be desirable for certain parameter values if it induces the private firm to change technology.

This study could, in future research, be extended in several directions. It would also be interesting to study alternative timings during the competition phase in quantities. We could also analyze the impact of a partial privatization of the public firm or of foreign investors holding a share of the private firm's capital.

8 Appendix

8.1 Cournot competition

8.1.1 Private duopoly

Both firms have dedicated technology: We calculate the best response from each firm:

$$\pi_1\left(q_1^A, q_2^B\right) = p^A\left(q_1^A, q_2^B\right) q_1^A - \left(q_1^A\right)^2 - F_D = \left(a - q_1^A - \lambda q_2^B\right) q_1^A - \left(q_1^A\right)^2 - F_D$$

$$\frac{\partial \pi_1}{\partial q_1^A}\left(q_1^A, q_2^B\right) = 0 \Leftrightarrow q_1^A = \frac{1}{4}\left(a - \lambda q_2^B\right)$$

Equilibrium quantities:

$$\left\{ \begin{array}{l} q_1^A = \frac{1}{4}\left(a - \lambda q_2^B\right) \\ q_2^B = \frac{1}{4}\left(a - \lambda q_1^A\right) \end{array} \right\} \Leftrightarrow \left\{ \begin{array}{l} q_1^A = \frac{1}{4+\lambda} a \\ q_2^B = \frac{1}{4+\lambda} a \end{array} \right\}$$

Both firms have flexible technology:

$$\pi_1\left(q_1^A, q_2^A, q_1^B, q_2^B\right) = p^A\left(q_1^A, q_2^A, q_1^B, q_2^B\right) q_1^A - \left(q_1^A\right)^2 + p^B\left(q_1^A, q_2^A, q_1^B, q_2^B\right) q_1^B - \left(q_1^B\right)^2 - F_F$$

$$\begin{aligned} \frac{\partial \pi_1}{\partial q_1^A}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^A - q_2^A - 2\lambda q_1^B - \lambda q_2^B = 0 \\ \frac{\partial \pi_1}{\partial q_1^B}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^B - q_2^B - 2\lambda q_1^A - \lambda q_2^A = 0 \end{aligned}$$

Cournot equilibrium:

$$\left\{ \begin{array}{l} a - 4q_1^A - q_2^A - 2\lambda q_1^B - \lambda q_2^B = 0 \\ a - 4q_1^B - q_2^B - 2\lambda q_1^A - \lambda q_2^A = 0 \\ a - q_1^A - 4q_2^A - \lambda q_1^B - 2\lambda q_2^B = 0 \\ a - q_1^B - 4q_2^B - \lambda q_1^A - 2\lambda q_2^A = 0 \end{array} \right\} \Leftrightarrow q_1^A = q_2^A = q_1^B = q_2^B = \frac{1}{5+3\lambda} a$$

Firms have different technologies: We will assume that firm 1 has a dedicated technology. We characterize its best response to firm 2 productions:

$$\begin{aligned} \pi_1\left(q_1^A, q_2^A, q_2^B\right) &= p^A\left(q_1^A, q_2^A, q_2^B\right) q_1^A - \left(q_1^A\right)^2 - F_D = \left(a - q_1^A - q_2^A - \lambda q_2^B\right) q_1^A - \left(q_1^A\right)^2 - F_D \\ \frac{\partial \pi_1}{\partial q_1^A}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^A - q_2^A - \lambda q_2^B = 0 \end{aligned}$$

We determine the best replies from firm 2 (which has flexible technology):

$$\pi_2\left(q_1^A, q_2^A, q_2^B\right) = p^A\left(q_1^A, q_2^A, q_2^B\right) q_2^A - \left(q_2^A\right)^2 + p^B\left(q_1^A, q_2^A, q_2^B\right) q_2^B - \left(q_2^B\right)^2 - F_F$$

$$\begin{aligned} \frac{\partial \pi_2}{\partial q_2^A}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - 4q_2^A - q_1^A - 2\lambda q_2^B = 0 \\ \frac{\partial \pi_2}{\partial q_2^B}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - 4q_2^B - \lambda q_1^A - 2\lambda q_2^A = 0 \end{aligned}$$

Cournot equilibrium:

$$\left\{ \begin{array}{c} a-4q_1^A-q_2^A-\lambda q_2^B=0 \\ a-4q_2^A-q_1^A-2\lambda q_2^B=0 \\ a-4q_2^B-\lambda q_1^A-2\lambda q_2^A=0 \end{array} \right\} \Leftrightarrow \left\{ \begin{array}{l} q_2^A=\frac{12-7\lambda+\lambda^2}{4(15-4\lambda^2)}a \\ q_1^A=\frac{6-\lambda-\lambda^2}{2(15-4\lambda^2)}a \\ q_2^B=\frac{3(5-3\lambda)}{4(15-4\lambda^2)}a \end{array} \right\}$$

8.1.2 Mixed duopoly

Both firms have dedicated technology: This case is similar to the case without merger in Bárcena-Ruiz and Garzón (2003).

The private firm seeks to maximize its profit. Its best reply to the quantity produced by the public firm is therefore given by:

$$\pi_1\left(q_1^A,q_2^B\right)=p^A\left(q_1^A,q_2^B\right)q_1^A-\left(q_1^A\right)^2-F_D=\left(a-q_1^A-\lambda q_2^B\right)q_1^A-\left(q_1^A\right)^2-F_D$$

$$\frac{\partial\pi_1}{\partial q_1^A}\left(q_1^A,q_2^B\right)=0\Leftrightarrow q_1^A=\frac{1}{4}\left(a-\lambda q_2^B\right)$$

The public firm seeks to maximize the social surplus. Its best response to the quantity produced by the private firm is obtained as follows:

$$TS\left(q_1^A,q_2^B\right)=p^A\left(q_1^A,q_2^B\right)q_1^A-\left(q_1^A\right)^2-F_D+p^B\left(q_1^A,q_2^B\right)q_2^B-\left(q_2^B\right)^2-F_D+\frac{1}{2}\left[\left(q_1^A\right)^2+\left(q_2^B\right)^2\right]+\lambda q_1^Aq_2^B$$

$$\frac{\partial TS}{\partial q_2^B}\left(q_1^A,q_2^B\right)=0\Leftrightarrow q_2^B=\frac{1}{3}\left(a-\lambda q_1^A\right)$$

Cournot equilibrium:

$$\left\{ \begin{array}{l} q_1^A=\frac{1}{4}\left(a-\lambda q_2^B\right) \\ q_2^B=\frac{1}{3}\left(a-\lambda q_1^A\right) \end{array} \right\} \Leftrightarrow \left\{ \begin{array}{l} q_1^A=\frac{3-\lambda}{12-\lambda^2}a \\ q_2^B=\frac{4-\lambda}{12-\lambda^2}a \end{array} \right\}$$

It should be noted that $q_2^B>q_1^A$. This is a classic result in mixed duopolies. The state-owned firm takes into account the impact of an increase in its production on consumers. It therefore produces more than a private firm would in a private duopoly.[17] As quantities are strategic substitutes, the private firm reacts to this increase in production by reducing its own production.

Both firms have flexible technology: We start by determining the best replies from the private firm:

$$\pi_1\left(q_1^A,q_2^A,q_1^B,q_2^B\right)=p^A\left(q_1^A,q_2^A,q_1^B,q_2^B\right)q_1^A-\left(q_1^A\right)^2+p^B\left(q_1^A,q_2^A,q_1^B,q_2^B\right)q_1^B-\left(q_1^B\right)^2-F_F$$

$$=\left(a-q_1^A-q_2^A-\lambda q_1^B-\lambda q_2^B\right)q_1^A-\left(q_1^A\right)^2+\left(a-q_1^B-q_2^B-\lambda q_1^A-\lambda q_2^A\right)q_1^B-\left(q_1^B\right)^2-F_F$$

[17] The marginal cost of the public firm is equal to the equilibrium price of the good B:

$$Cm_2\left(q_2^B\right)=2q_2^B=2\frac{4-\lambda}{12-\lambda^2}a=p^B=\frac{8-2\lambda}{12-\lambda^2}a$$

$$\begin{aligned}\frac{\partial \pi_1}{\partial q_1^A}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^A - q_2^A - 2\lambda q_1^B - \lambda q_2^B = 0 \\ \frac{\partial \pi_1}{\partial q_1^B}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^B - q_2^B - 2\lambda q_1^A - \lambda q_2^A = 0\end{aligned}$$

We then characterize the best replies of the public firm:

$$\begin{aligned}TS\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= p^A(.)\, q_1^A - \left(q_1^A\right)^2 + p^B(.)\, q_1^B - \left(q_1^B\right)^2 + p^A(.)\, q_2^A - \left(q_2^A\right)^2 + p^B(.)\, q_2^B - \left(q_2^B\right)^2 \\ &\quad -2F_F + \frac{1}{2}\left[\left(q_1^A + q_2^A\right)^2 + \left(q_1^B + q_2^B\right)^2\right] + \lambda\left(q_1^A + q_2^A\right)\left(q_1^B + q_2^B\right)\end{aligned}$$

$$\begin{aligned}\frac{\partial TS}{\partial q_2^A}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - q_1^A - 3q_2^A - \lambda q_1^B - \lambda q_2^B = 0 \\ \frac{\partial TS}{\partial q_2^B}\left(q_1^A, q_2^A, q_1^B, q_2^B\right) &= 0 \Leftrightarrow a - q_1^B - 3q_2^B - \lambda q_1^A - \lambda q_2^A = 0\end{aligned}$$

Cournot equilibrium:

$$\left\{\begin{array}{c} a - 4q_1^A - q_2^A - 2\lambda q_1^B - \lambda q_2^B = 0 \\ a - 4q_1^B - q_2^B - 2\lambda q_1^A - \lambda q_2^A = 0 \\ a - q_1^A - 3q_2^A - \lambda q_1^B - \lambda q_2^B = 0 \\ a - q_1^B - 3q_2^B - \lambda q_1^A - \lambda q_2^A = 0 \end{array}\right\} \Leftrightarrow \left\{\begin{array}{l} q_2^A = q_2^B = \frac{3+\lambda}{11+8\lambda+\lambda^2} a \\ q_1^A = q_1^B = \frac{2}{11+8\lambda+\lambda^2} a \end{array}\right\}$$

As in the previous case, it can be noted that the output of the public firm is higher than that of the private firm.

The private firm has a dedicated technology and the public firm is flexible: Best response from the private firm:

$$\begin{aligned}\pi_1\left(q_1^A, q_2^A, q_2^B\right) &= p^A\left(q_1^A, q_2^A, q_2^B\right) q_1^A - \left(q_1^A\right)^2 - F_D \\ \frac{\partial \pi_1}{\partial q_1^A}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - 4q_1^A - q_2^A - \lambda q_2^B = 0\end{aligned}$$

Best response from the state-owned firm:

$$\begin{aligned}TS\left(q_1^A, q_2^A, q_2^B\right) &= p^A(.)\, q_1^A - \left(q_1^A\right)^2 - F_D + p^A(.)\, q_2^A - \left(q_2^A\right)^2 + p^B(.)\, q_2^B - \left(q_2^B\right)^2 - F_F \\ &\quad + \frac{1}{2}\left[\left(q_1^A + q_2^A\right)^2 + \left(q_2^B\right)^2\right] + \lambda\left(q_1^A + q_2^A\right) q_2^B\end{aligned}$$

$$\begin{aligned}\frac{\partial TS}{\partial q_2^A}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - q_1^A - 3q_2^A - \lambda q_2^B = 0 \\ \frac{\partial TS}{\partial q_2^B}\left(q_1^A, q_2^A, q_2^B\right) &= 0 \Leftrightarrow a - 3q_2^B - \lambda q_1^A - \lambda q_2^A = 0\end{aligned}$$

Cournot equilibrium:

$$\left\{\begin{array}{c} a - 4q_1^A - q_2^A - \lambda q_2^B = 0 \\ a - q_1^A - 3q_2^A - \lambda q_2^B = 0 \\ a - 3q_2^B - \lambda q_1^A - \lambda q_2^A = 0 \end{array}\right\} \Leftrightarrow \left\{\begin{array}{l} q_1^A = \frac{2(3-\lambda)}{33-5\lambda^2} a \\ q_2^A = \frac{3(3-\lambda)}{33-5\lambda^2} a \\ q_2^B = \frac{11-5\lambda}{33-5\lambda^2} a \end{array}\right\}$$

The private firm is flexible and the public firm has a dedicated technology: Best replies from the private firm:

$$\begin{aligned}\pi_1\left(q_1^A,q_1^B,q_2^B\right) &= p^A\left(q_1^A,q_1^B,q_2^B\right)q_1^A-\left(q_1^A\right)^2+p^B\left(q_1^A,q_1^B,q_2^B\right)q_1^B-\left(q_1^B\right)^2-F_F\\ &= \left(a-q_1^A-\lambda q_1^B-\lambda q_2^B\right)q_1^A-\left(q_1^A\right)^2+\left(a-q_1^B-q_2^B-\lambda q_1^A\right)q_1^B-\left(q_1^B\right)^2-F_F\end{aligned}$$

$$\begin{aligned}\frac{\partial\pi_1}{\partial q_1^A}\left(q_1^A,q_1^B,q_2^B\right) &= 0\Leftrightarrow a-4q_1^A-2\lambda q_1^B-\lambda q_2^B=0\\ \frac{\partial\pi_1}{\partial q_1^B}\left(q_1^A,q_1^B,q_2^B\right) &= 0\Leftrightarrow a-4q_1^B-q_2^B-2\lambda q_1^A=0\end{aligned}$$

Best reply from the public firm:

$$\begin{aligned}TS\left(q_1^A,q_1^B,q_2^B\right) &= p^A(.)\,q_1^A-\left(q_1^A\right)^2+p^B(.)\,q_1^B-\left(q_1^B\right)^2-F_F+p^B(.)\,q_2^B-\left(q_2^B\right)^2-F_D\\ &\quad+\frac{1}{2}\left[\left(q_1^A\right)^2+\left(q_1^B+q_2^B\right)^2\right]+\lambda q_1^A\left(q_1^B+q_2^B\right)\end{aligned}$$

$$\frac{\partial TS}{\partial q_2^B}\left(q_1^A,q_1^B,q_2^B\right)=0\Leftrightarrow a-q_1^B-3q_2^B-\lambda q_1^A=0$$

Cournot equilibrium:

$$\left\{\begin{array}{c}a-4q_1^A-2\lambda q_1^B-\lambda q_2^B=0\\ a-4q_1^B-q_2^B-2\lambda q_1^A=0\\ a-q_1^B-3q_2^B-\lambda q_1^A=0\end{array}\right\}\Leftrightarrow\left\{\begin{array}{c}q_1^A=\frac{11-7\lambda}{4(11-3\lambda^2)}a\\ q_2^B=\frac{12-2\lambda-2\lambda^2}{4(11-3\lambda^2)}a\\ q_1^B=\frac{8-5\lambda+\lambda^2}{4(11-3\lambda^2)}a\end{array}\right\}$$

8.2 Impact of privatisation on the welfare

8.2.1 In zone 5

Privatization has no impact on the equilibrium technological configuration, which is (F,F) in both types of duopoly. By comparing the social surpluses, we obtain that privatization increases the social surplus if and only if:

$$\frac{4\left(3+2\lambda\right)}{\left(5+3\lambda\right)^2}a^2-2F_F\geq\frac{59+55\lambda+13\lambda^2+\lambda^3}{\left(11+8\lambda+\lambda^2\right)^2}a^2-2F_F\Leftrightarrow\frac{4\left(3+2\lambda\right)\left(11+8\lambda+\lambda^2\right)^2}{\left(59+55\lambda+13\lambda^2+\lambda^3\right)\left(5+3\lambda\right)^2}\geq 1$$

The left-hand ratio of the inequality is always less than 1. So this condition is never fulfilled. In this area, privatization leads to a reduction in the social surplus.

8.2.2 In zone 3

Privatization does not change the technological equilibrium,[18] which remains (D,F). Privatization causes an increase in the social surplus if and only if:

$$\frac{2853-1206\lambda-1000\lambda^2+438\lambda^3+3\lambda^4}{32\left(15-4\lambda^2\right)^2}a^2-F_D-F_F\geq\frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2}a^2-F_D-F_F$$

[18] After privatization, the two firms can reverse their technological choice and move to equilibrium (F,D), but this has no impact on the social surplus.

$$\Leftrightarrow \frac{\left(2853-1206\lambda-1000\lambda^2+438\lambda^3+3\lambda^4\right)\left(33-5\lambda^2\right)^2}{32\left(15-4\lambda^2\right)^2\left(447-177\lambda-63\lambda^2+25\lambda^3\right)} \geq 1$$

This condition is never verified. Privatization therefore reduces the social surplus in zone 3.

8.2.3 In zone 2

In zone 2, the privatisation of the public firm led to a change in the equilibrium technological configuration from (D, F) to (D, D). Privatization increases the social surplus if and only if:

$$\begin{aligned} \frac{5+\lambda}{(4+\lambda)^2}a^2-2F_D &\geq \frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2}a^2-F_D-F_F \\ &\Leftrightarrow \frac{s}{a^2} \geq \frac{447-177\lambda-63\lambda^2+25\lambda^3}{\left(33-5\lambda^2\right)^2}-\frac{5+\lambda}{(4+\lambda)^2} \end{aligned}$$

This inequality is never verified. The privatization of the public firm leads to a reduction in the social surplus.

8.2.4 In zone 1

Privatization has no impact on the technological equilibrium configuration, which is (D,D) in both cases. By comparing the social surpluses, we obtain that privatization increases the social surplus if and only if:

$$\frac{5+\lambda}{(4+\lambda)^2}a^2-2F_D \geq \frac{93-30\lambda-6\lambda^2+2\lambda^3}{2\left(12-\lambda^2\right)^2}a^2-2F_D \Leftrightarrow \frac{2\left(5+\lambda\right)\left(12-\lambda^2\right)^2}{(4+\lambda)^2\left(93-30\lambda-6\lambda^2+2\lambda^3\right)} \geq 1$$

This inequality is never verified. The privatization of the public firm leads to a reduction in the social surplus.

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