Adoption Strategies with an
Imperfectly Competitive Technology Market

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Abstract

In this paper, we analyze how the market structure of the technology market affects the outcome of an adoption race. We propose a model of adoption of a new production technology in line with the existing literature, but in contrast with the literature, we assume that the upstream innovator has market power. We find that, when the upstream market is monopolistic, in equilibrium, there is no preemption race between downstream firms. When only one downstream firm can adopt the new technology, adoption occurs at the stand-alone date of the downstream firms. When two downstream firms can compete to adopt the new technology, one firm (the “leader”) adopts later than the preemption date and earlier than the stand-alone date, while the other firm (the “follower”) adopts also later than with a competitive technology market. The delay is induced by the monopolistic upstream innovator, through a specific time-dependent pricing scheme. Finally, we introduce a possibility of imitation to study how the introduction date of the innovation is affected by potential competition in the technology market.

Keywords: Adoption Race; Licensing; Technology Market.

JEL Codes: D21; D43; L13.
1 Introduction

The adoption of a new production technology is an important decision for a firm, as it determines its future cost structure and it may also provide a competitive advantage over its competitors. In many industries, however, firms do not develop new production technologies in-house, but rather purchase the new technology from an upstream supplier in a technology market. For example, in the telecommunications industry, telecom operators purchase network equipments from such suppliers as Alcatel-Lucent, Ericsson or Nokia Siemens Networks. These suppliers are also responsible for most of the innovations in network infrastructures.\(^1\)

Though firms like Alcatel-Lucent or Ericsson have had strong positions in this technology market for a long time, they have been recently challenged by new entrants such as Huawei, a Chinese company founded in 1988, which experienced a rapid growth of its business in the early 2000s, rising up to compete with Nokia Siemens Networks as the No. 2 in the global mobile infrastructure equipment market in 2009.

This example suggests the market power of technology suppliers can vary from market to market, or from time to time. How does the competitiveness of the upstream technology market affect the adoption of new technologies by downstream firms? This is the focus of the present paper.

To answer this question, we propose a model of technology adoption, in line with the canonical model proposed by Fudenberg and Tirole (1985) and Katz and Shapiro (1987). We assume that there are two vertically related markets: an upstream technology market, and a downstream production market. In the downstream market, firms use an old technology. At the beginning of the game, a new technology is invented in the upstream market, whose fixed cost decreases over time. We study the downstream firms’ adoption strategies, by contrasting two market structures in the upstream technology market: (i) perfect competition, and (ii) monopoly.

\(^1\)For instance, in 2009, Nokia Siemens Networks reported that R&D expenses amounted for 18.1% of its net sales, and Alcatel-Lucent 13.3%. 
We start by studying a simple model with a single producer in the downstream market. When the technology market is competitive, the downstream firm adopts the new technology at its stand-alone date. We then consider the opposite case, where the upstream market is controlled by a monopoly provider, which can set a time-dependent fixed price for the new technology. We show that the equilibrium adoption date is the same as with a competitive technology market; the downstream firm also adopts at its stand-alone date, and the upstream monopoly extracts the industry surplus through the fixed price for the new technology.

We then study whether this neutrality result is valid when there is competition in the downstream market. We modify our basic model and assume that two firms compete in the downstream market. At the beginning of the game, they both use the old technology, and we study their adoption strategies in a dynamic game with continuous time and infinite horizon. As a benchmark, we study the case where the upstream market is competitive, which corresponds to the standard case in the adoption literature. Similar to the literature, we show that in equilibrium there is either preemption –the leader adopts at the preemption date– or waiting –the leader adopts at its stand-alone date.

We distinguish two different cases when the upstream market is monopolistic. When there is room for only one adoption, we show that with an upstream monopoly, adoption occurs at a date which is between the preemption date and the stand-alone date. When the two downstream firms can adopt the new technology, we show that one firm (the “leader”) adopts the new technology at its stand-alone date, whereas the other (the “follower”) adopts the new technology at a date which is later than with a competitive technology market. Therefore, a monopoly technology provider delays the adoption of both the leader and the follower. Besides, the result of the literature that there is “rent dissipation” is no longer valid when the technology market is monopolistic.

This paper is related to two strands of literature: the adoption literature, and the licensing literature.
Our paper is most closely related to the adoption literature. Gilbert and Newbery (1982) show that a monopolist innovator has a strong incentive to use preemptive patenting to foreclose potential new entrants. However, most of the adoption literature considers a setting in which the technology market is perfectly competitive, that is, technology firms license their technology (or sell their inputs) at cost. This cost is typically assumed to be exogenous and decreasing over time, because of learning-by-doing effects or declines in component prices. The literature analyzes the strategies of two competing firms with regards to the adoption of the new technology. The seminal contribution is Reinganum (1981). In a duopolistic market, the adoption of the new cost-reducing technology allows the adopter to increase its profit flow. Due to a business-stealing effect, and since the adoption by one firm exerts a negative impact on the profit flow of its competitor, Reinganum shows that there is a first-mover advantage and sequential adoptions. Fudenberg and Tirole (1985) show that, if the firms are not able to precommit to their adoption timing—for instance, because information lags about the other firms’ actions are small or non-existent—the firms will race to preempt each other. Therefore, there is preemption and rent dissipation in equilibrium. In their model, the cost of adopting the new technology is exogenous and decreasing over time, because of learning-by-doing effects or declines in component prices. Increased efficiencies in the technology market are passed to the downstream firms, suggesting that the innovator has no market power. This baseline adoption model has been extended by various authors (for example, see Katz and Shapiro (1987), Riordan (1992), Hendricks (1992), Götz (1999)).

Some contributions in this literature study the factors which may lower why preemption incentives, such as uncertainty about the value of the innovation (Jensen, 1982; Cabral and Dezso, 2008), informational spillovers from the first acquisition (Mariotti, 1992), or time-consuming deployment of the innovation (Ruiz-Aliseda and Zemsky, 2006). Our paper contributes to the adoption literature by lifting the assumption that the technology market is perfectly competitive. We show that this assumption is crucial for the existence of preemptive equilibria.

This paper is also related to the licensing literature, which considers a monopolist inventor of an innovative process or product, which is protected by a patent (see, among others, Katz and Shapiro (1986), Kamien and Tauman (1986), and Gallini and Wright (1990)). The literature shows that an innovator, which is specialized in R&D, sells its license to only one firm to extract downstream monopoly profits; to that end, the licensor sets a zero royalty rate and extracts all rents through a fixed fee (e.g., see Tirole, 1988). Recent contributions in this literature relax the assumption of a monopolistic patentholder (for instance, see Arora and Fosfuri, 2003).

The rest of the paper is structured as follows. In Section 2, we introduce a basic model with a single potential adopter. In Section 3 we introduce competition in the downstream market. Section 4 analyzes the impact of imitation on of the innovator. Finally, we conclude.

2 A basic model with a monopolistic downstream market

In this section, we introduce our setting and show that, when the downstream market is monopolistic, the structure of the upstream market (whether it is perfectly competitive or monopolistic) does not affect the equilibrium date of adoption of the new technology.

2.1 The setting

There are two firms, an innovator (firm I) which operates in an upstream technology market, and a pure downstream firm (firm 1). At the beginning of the game, firm 1 uses an “old” production technology, with a marginal cost of \( c \). However, firm I has developed a “new” production technology, which lowers the marginal cost to \( c' < c \).

For firm I, the cost of selling the new technology to firm 1 at time \( t \) is \( C(t) \), and we assume that \( C'(t) < 0, C''(t) > 0 \), and that \( \lim_{t \to \infty} C(t) = 0 \).\(^3\) Let \( \delta \) denote the discount rate. The discounted cost of the new technology to time zero is then \( A(t) = e^{-\delta t}C(t) \); given our

\(^3\)For instance, the “new” technology could be a new production equipment, whose cost decreases over time due to an exogenous technological progress.
assumptions on $C(t)$, note that we have $A'(t) < 0$. We also define $Z(t) = -A'(t)e^{\delta t} = \delta C(t) - C'(t)$. Note that $Z'(t) < 0$.

We denote by $\pi^m(c)$ the monopoly profit flow of firm 1 for a marginal cost of $c$, with the standard assumption that $\partial \pi^m(c)/\partial c < 0$. Finally, we assume that adoption never occurs at date 0, which is the case if $\delta C(0) < \pi^m(\xi)$.

We consider the following game. In period 1, firm $I$ decides on a price scheme $F(t)$ for the new technology, which depends on time.\(^4\) Then, in period 2, after observing firm $I$’s price scheme, firm 1 decides if and when to adopt the new technology.

If firm 1 does not purchase the new technology from firm $I$ at any date, its discounted profit writes
\[
\Pi_{1NA} = \int_0^\infty e^{-\delta t} \pi^m(\xi) dt = \frac{\pi^m(\xi)}{\delta},
\]
where the superscript “NA” stands for “No Adoption”. If firm 1 purchases the technology at date $T$, its discounted profit is
\[
\Pi_1(T) = \int_0^T e^{-\delta t} \pi^m(\xi) dt + \int_T^\infty e^{-\delta t} \pi^m(\xi) dt - F(T). \tag{1}
\]

2.2 The equilibrium

We now determine the equilibrium of this game when the technology market is competitive, and when it is monopolistic.

**Competitive technology market** As a benchmark, we consider a situation where the technology market is perfectly competitive, that is, for all $t$, we have $F(t) = A(t)$, which corresponds to the standard assumption in the adoption literature. If firm 1 decides to purchase the new technology, it chooses an adoption date $T$ to maximize its profit $\Pi_1(T)$, with $F(\cdot) = A(\cdot)$.

\(^4\)For simplicity of exposition, we consider that $F(t)$ represents the discounted price to time zero of the new technology.
Therefore, the equilibrium adoption date is given by

\[ \tilde{T}^* = \arg \max_T \Pi_1 (T) = \int_T^\infty e^{-\delta t} (\pi^m (\ell) - \pi^m (\tau)) \, dt - A (T). \]

In the adoption literature, this date is referred to as firm 1’s *stand-alone date*.

Firm 1 decides to obtain the license if and only if \( \Pi_1 (\tilde{T}^*) \geq \Pi_1^{NA} \) and we assume that this is the case.

**Monopolistic technology market** We now turn to our setting where firm I is a monopolist in the upstream technology market. Given the price scheme \( F (t) \) chosen by firm I, firm 1 adopts at a given date \( T \) if \( \Pi_1 (T) \geq \Pi_1^{NA} \), and if \( \Pi_1 (x) \) is maximized at \( T \).

Given firm 1’s adoption decision rule, in period 1, firm I decides on a price scheme \( F (t) \).

To begin with, note that firm I can implement a price scheme such that adoption takes place at any given date \( T \). To do so, firm I can set a prohibitively high fee for the new technology before date \( T \), then propose an attractive price at this very date, and finally raise the price again afterwards.\(^5\) Therefore, firm I’s choice of a price scheme \( F (t) \) can be reformulated in terms of a choice of an adoption date \( T \). Firm I’s program can then be written as

\[ \max_T \Pi_I = F (T) - A (T), \]

s.t.

\[ \Pi_1 (T) \geq \Pi_1^{NA}, \tag{2} \]

where \( \Pi_1 (T) \) is given by (1), and

\[ \Pi_1 (T) \geq \Pi_1 (\tilde{T}) \text{ for all } \tilde{T} \in [0, \infty). \]

\(^5\)Alternatively, we could assume that firm I introduces the new technology at date \( T \), at a constant price \( F \). Firm 1 would then have an incentive to adopt immediately.
This program means that firm $I$ maximizes its discounted profit from the sale of the new technology $(F(T) - A(T))$ subject to two constraints. The first constraint means that firm $I$ prefers adopting the new technology at date $T$ than never adopting it. The second constraint states that, provided that firm 1 adopts the new technology, its optimal adoption date is equal to $T$.

To start with, note that the second constraint does not play any role, since firm $I$ can set a very high price for dates earlier or later than its optimal date of adoption. As for condition (2), if it were not binding, then firm $I$ could raise the price of the new technology at date $T$ (i.e., $F(T)$) until this is the case. Therefore, condition (2) is necessarily binding. Using that $\Pi_1(T) = \Pi_{1NA}$, the program of firm $I$ is equivalent to maximizing the following expression:

$$\int_{T}^{\infty} e^{-\delta t} (\pi^m(c) - \pi^m(\tau)) dt - A(T).$$

This is the same program as in the case of a competitive technology market, that is, we have $T^* = \tilde{T}^*$. Therefore, we can state the following proposition.

**Proposition 1** With a monopolistic downstream market, the downstream firm adopts the technology at the same date whether the upstream technology market is monopolistic or competitive.

Since industry profits are maximized when adoption occurs at the stand-alone date, the upstream monopoly implements a price scheme such that adoption occurs at this date.$^6$ Note that firm $I$ can implement the same equilibrium by introducing its technology at date $T^*$ at a price of $F(T^*)$. We will also use this interpretation in the rest of the text.

$^6$Therefore, our result also holds with efficient bargaining if the upstream firm and the downstream firm share the surplus generated by the transaction.
3 Competitive downstream market

In this section, we introduce competition in the downstream market. We assume that there are two downstream firms, firm 1 and firm 2. At the beginning of the game, the two downstream firms use the old technology. Then, given the price scheme $F(t)$ for the new technology and the history of adoption decisions, at each moment of time, each downstream firm $i = 1, 2$ decides whether to adopt the new technology.

We will say that the innovation is drastic if $p^m (c) < \bar{c}$, whereas it is non-drastic if $p^m (c) \geq \bar{c}$. With a non-drastic innovation, firm $i$’s profit flow depends on whether it has adopted the new technology, and also on whether its downstream competitor has adopted the new technology. We denote firm $i$’s profit flow by $\pi^d (c_i, c_j)$, where $c_i$ and $c_j$ denote firm $i$’s and firm $j$’s marginal costs, respectively, with $i, j = 1, 2$ and $j \neq i$, and $c_i, c_j \in \{c, \bar{c}\}$.

In what follows, we start by determining the equilibrium when only one downstream firm can adopt the new technology (“exclusivity”). Then, we analyze the other case, where the two downstream firms can adopt the new technology (“no exclusivity”).

3.1 Exclusivity

We assume that only one downstream firm can adopt the new technology. As in our basic model in Section 2, we start by determining the equilibrium in a benchmark situation where the technology market is perfectly competitive. Then, we determine the equilibrium with a monopolistic upstream firm.

3.1.1 Competitive technology market

If the technology market is perfectly competitive, then we have $F(t) = A(t)$, for all $t$. Given this assumption, we determine the equilibrium of the adoption game.
Assume that no downstream firm has adopted the new technology at date $T$. If firm $i = 1, 2$ adopts the new technology at date $T$ (i.e., firm $i$ “wins” the adoption race) its discounted profit is

$$\Pi_i (T) = \int_0^T e^{-\delta t} \pi^d (\tau, \bar{\tau}) \, dt + \int_T^\infty e^{-\delta t} \pi^m (\xi, \bar{\xi}) \, dt - A(T),$$

if the innovation is drastic, and

$$\Pi_i (T) = \int_0^T e^{-\delta t} \pi^d (\tau, \bar{\tau}) \, dt + \int_T^\infty e^{-\delta t} \pi^d (\xi, \bar{\xi}) \, dt - A(T),$$

otherwise.

These profit expressions read as follows. From date 0 to date $T$, the two downstream firms use the old technology and earn the duopoly profit flows $\pi^d (\tau, \bar{\tau})$. Then, at date $T$, firm $i$ adopts the new technology. Therefore, if the innovation is non-drastic, from date $T$ on, firm $i$ earns the duopoly profit flow $\pi^d (\xi, \bar{\xi})$, whereas firm $j$ earns the duopoly profit flow $\pi^d (\tau, \bar{\tau}) < \pi^d (\xi, \bar{\xi})$. If the innovation is drastic, from date $T$ on, firm $i$ earns the monopoly profit flow $\pi^m (\xi)$, whereas firm $j$ earns zero profit.

If firm $i$ does not adopt the new technology, but firm $j$ does, that is, firm $i$ “loses” the adoption race, firm $i$’s discounted profit writes

$$\Pi_i^{NA} (T) = \int_0^T e^{-\delta t} \pi^d (\tau, \bar{\tau}) \, dt,$$

if the innovation is drastic, and

$$\Pi_i^{NA} (T) = \int_0^T e^{-\delta t} \pi^d (\tau, \bar{\tau}) \, dt + \int_T^\infty e^{-\delta t} \pi^d (\xi, \bar{\xi}) \, dt,$$

otherwise.

We define firm $i$’s preemption date, $T_i^P$, as the earliest date $T$ such that $\Pi_i (T) \geq \Pi_i^{NA} (T)$. Since firm 1 and firm 2 are identical, we have $T_1^P = T_2^P = T^P$. The following Lemma shows
that the preemption date $T^P$ corresponds to the threshold date at which each downstream firm is willing to adopt the new technology.

**Lemma 1** There is a unique date $T^P \in (0, \infty)$ such that $\Pi_i(T) \geq \Pi_i^{NA}(T)$ if $T \geq T^P$, and $\Pi_i(T) < \Pi_i^{NA}(T)$ otherwise.

**Proof.** See Appendix A. ■

The preemption date $T^P$ is defined by $\Pi_i(T) = \Pi_i^{NA}(T)$, that is,

$$\int_T^\infty e^{-\delta t} \pi^m(c) \, dt = A(T),$$

if the innovation is drastic, and

$$\int_T^\infty e^{-\delta t} \left( \pi^d(c) - \pi^d(c, \bar{c}) \right) \, dt = A(T),$$

otherwise. To determine the equilibrium, we compare the preemption date to the stand-alone date, which is defined as the date which maximizes the leader’s profit, which is

$$\int_0^T e^{-\delta t} \pi^d(c) \, dt + \int_T^\infty e^{-\delta t} \pi^m(c) \, dt - A(T),$$

if the innovation is drastic, and

$$\int_0^T e^{-\delta t} \pi^d(c) \, dt + \int_T^\infty e^{-\delta t} \pi^d(c, \bar{c}) \, dt - A(T),$$

otherwise.

If the preemption date is earlier than the stand-alone date, then in equilibrium, there is preemption, and one downstream firm adopts the new technology at date $T^P$. Since our focus is how the possibility of a preemption equilibrium is influenced by the market structure in the upstream market, we assume that this the case.
3.1.2 Monopolistic technology market

Now, we consider that firm \( I \) is a monopoly in the upstream technology market. As only one downstream firm can adopt the new technology, we can follow the same reasoning as in Section 2 and consider that everything is as if firm \( I \) could set the adoption date \( T \).\(^7\) Assume, without loss of generality, that firm 1 adopts at date \( T \). Then, firm \( I \) has the following program,

\[
\max_T F(T) - C(T)
\]

s.t.

\[
\Pi_1(T) \geq \Pi_1^{NA}
\]

and

\[
\Pi_i(\tilde{T}) < \Pi_i^{NA} \text{ for all } \tilde{T} < T \text{ and } i = 1, 2.
\]

The first constraint means that firm 1 prefers adopting the new technology than not adopting it. The second constraint states that no downstream firm has incentives to adopt at an earlier date. Note that this constraint is easily fulfilled as firm \( I \) can set a prohibitive price prior to date \( T \).

Since firm \( I \) can raise the price of the new technology until condition (3) is binding, we have \( \Pi_1(T) = \Pi_1^{NA} \), which implies that the problem is equivalent to a problem where firm \( I \) chooses the adoption date \( T \) so as to maximize

\[
\int_T^\infty e^{-\delta t} \pi_m(c) \, dt - A(T),
\]

\(^7\)As above, we could alternatively assume that firm \( I \) “introduces” the new technology at date \( T \), at a constant price \( F \). Given that the price is constant, a downstream firm would adopt the new technology immediately.
if the innovation is drastic, and

\[ 
\int_{T}^{\infty} e^{-\delta t} \left( \pi^d(c, \bar{c}) - \pi^d(\bar{c}, \bar{c}) \right) dt - A(T), \tag{5} \]

otherwise. Note that this corresponds to the maximum bid firms 1 and 2 would propose to obtain an exclusivity over the new technology at date \( T \).

Remark that (4) and (5) equal to zero in a preemption equilibrium. Therefore, with a monopolistic technology market, in equilibrium, adoption occurs later than with a competitive technology market. Therefore, we have the following result.

**Proposition 2**  With imperfect competition in the downstream market, if the technology market is monopolistic and only one downstream firm can adopt the new technology, in equilibrium there is no preemptive race, and adoption occurs later than with a competitive technology market.

It is not in the interest of the upstream monopoly to trigger a preemption race between the two downstream firms, as it would dissipate the industry profits. Instead, the technology supplier delays the introduction date to maximize the downstream discounted profit (net of the adoption cost), which it captures through the price of the new technology.

Note that the objective functions (4) and (5) do not take into account the opportunity cost for the downstream firms of adopting the new technology, which is equal to \( \pi^d(\bar{c}, \bar{c}) \). This means that in equilibrium, adoption occurs earlier than the stand-alone date.

### 3.2 No exclusivity

So far, we have assumed that only one downstream firm can adopt the new technology. We now consider the case where the two downstream firms can adopt the new technology. We focus on the case where the innovation is non-drastic –the case where the innovation is drastic yields similar results.
3.2.1 Competitive technology market

**Follower’s problem** We start by assuming that one downstream firm, the “leader”, say firm \(i\), has adopted the new technology at some date \(t_i\), and we solve the follower’s problem in the continuation game. If it adopts the new technology at date \(t_j \geq t_i\), firm \(j\) makes a discounted profit of

\[
\Pi_j^F(t_i, t_j) = \int_0^{t_i} e^{-\delta t} \pi^d(\tau, \tau) \, dt + \int_{t_i}^{t_j} e^{-\delta t} \pi^d(\tau, c) \, dt + \int_{t_j}^{\infty} e^{-\delta t} \pi^d(c, c) \, dt - A(t_j)
\]

where the superscript “F” designates the follower. The follower’s discounted profit reads as follows. From date 0 to date \(t_i\), since no downstream firm has adopted the new technology, they both use the old technology and earn the profit flow \(\pi^d(\tau, \tau)\). From date \(t_i\) to date \(t_j\), firm \(i\) uses the new technology whereas firm \(j\) uses the old technology; firm \(j\) therefore obtains the profit flow \(\pi^d(\tau, c)\). Finally, from date \(t_j\), both firms use the new technology and earn the profit flow \(\pi^d(c, c)\).

The following Lemma defines the follower’s optimal adoption date.

**Lemma 2** In the continuation game, the follower adopts the new technology at date \(t_j^F = t^* = Z^{-1}(\pi^d(c, c) - \pi^d(\tau, \tau))\) if \(t^* \geq t_i\), and at date \(t_j^F = t_i\) otherwise.

**Proof.** See Appendix B. ■

If the leader’s adoption date is very late, the follower adopts immediately. Otherwise, the follower’s optimal adoption date does not depend on the leader’s adoption date.

In the following, to simplify notations, we note \(\Pi_j^F(t_i) = \Pi_j^F(t_i, t_j^F(t_i))\) the discounted profit of the follower at its optimal adoption date.
Leader’s problem and equilibrium  Given that firm $j$ follows at date $t^F (t_i)$, the discounted profit of the leader when it adopts at date $t_i$ writes

$$\Pi^L_i (t_i, t^F (t_i)) = \int_0^{t_i} e^{-\delta t} \pi^d (\bar{c}, \bar{c}) dt + \int_{t_i}^{t^F (t_i)} e^{-\delta t} \pi^d (\bar{c}, \bar{c}) dt + \int_{t^F (t_i)}^{\infty} e^{-\delta t} \pi^d (\bar{c}, \bar{c}) dt - A(t_i), \quad (6)$$

where the superscript “L” designates the leader. Replacing for $t^F (t_i)$ and using the notation $\Pi^L_i (t_i) = \Pi^L_i (t_i, t^F (t_i))$, equation (6) can be rewritten as

$$\Pi^L_i (t_i) = \frac{\pi^d (\bar{c}, \bar{c})}{\delta} \left( 1 - e^{-\delta t_i} \right) + \frac{\pi^d (\bar{c}, \bar{c}) - \pi^d (\bar{c}, \bar{c})}{\delta} e^{-\delta t_i} - A(t_i)$$

if $0 \leq t_i \leq t^*$, and

$$\Pi^L_i (t_i) = \frac{\pi^d (\bar{c}, \bar{c})}{\delta} \left( 1 - e^{-\delta t_i} \right) + \frac{\pi^d (\bar{c}, \bar{c}) - \pi^d (\bar{c}, \bar{c})}{\delta} e^{-\delta t_i} - A(t_i),$$

otherwise. We define the leader’s stand-alone adoption date, $T^S$, as follows:

$$T^S = \arg \max_T \Pi^L_i (T).$$

Note that in equilibrium, the leader never adopts later than $T^S$. However, as above, the downstream firms might compete to be the leader. We therefore define firm $i$’s preemption date, $T^P_i$, as the earliest date $T$ such that $\Pi^L_i (T) \geq \Pi^F_i (T)$. Since firm 1 and firm 2 are identical, we have $T^P_1 = T^P_2 = T^P$. The following Lemma is similar to Lemma 1.

**Lemma 3** There is a unique date $T^P \in (0, \infty)$ such that $\Pi^L_i (T) \geq \Pi^F_i (T)$ if $T \geq T^P$, and $\Pi^L_i (T) < \Pi^F_i (T)$ otherwise.

**Proof.** See Appendix C. □

We can now solve for the equilibrium.
Lemma 4 If $T^P < T^S$, in equilibrium, there is preemption and the leader adopts at date $T^P$. Otherwise, there is waiting and the leader adopts at date $T^S$.


This is a standard result in the adoption literature. If the preemption date is sufficiently early relative to the stand-alone date, the two potential adopters engage in a preemptive race to be the leader.

3.2.2 Monopolistic technology market

We now assume that firm $I$ is a monopoly in the upstream technology market. Firm $I$ decides on a price scheme $F(t)$ to maximize its profit,

$$
\Pi_I = F(t_1) - A(t_1) + F(t_2) - A(t_2),
$$

where $t_1$ and $t_2$ designate firm 1’s and firm 2’s adoption dates, respectively (provided that both firms actually adopt the new technology).

As in the previous sections, it turns out that firm $I$ can set the price scheme such that firm 1 adopts at a given date $t_1$ and firm 2 adopts at a given date $t_2$. To do so, firm $I$ can set a prohibitive price for the new technology before date $t_1$ and just after this date, until date $t_2$. From date $t_2$ on, firm $I$ can set a constant price $F(t_2) = F_2$. Given that the price of the new technology is constant, firm 2 adopts immediately at time $t_2$.

Therefore, firm $I$ has the following program,

$$
\max_{t_1, t_2} \Pi_I = F(t_1) - A(t_1) + F(t_2) - A(t_2),
$$

subject to three constraints: (i) firm 1 should prefer adopting at $t_1$ than adopting at $t_2$; (ii)

\footnote{Alternatively, we can consider that firm $I$ introduces the new technology at date $t_1$ at a constant price $F_1$ and then changes the price to $F_2$ at date $t_2$. Our analysis remains valid.}
firm 2 should prefer adopting at $t_2$ than adopting at $t_1$; (iii) firm 2 prefers adopting the new technology than never adopting it.

To begin with, consider constraint (iii). This constraint writes $\Pi^E_2(t_1,t_2) \geq \Pi^{NA}_2(t_1)$, where $\Pi^{NA}_2(t_1)$ represents firm 2’s discounted profit if it never adopts the new technology, given that firm 1 has adopted at date $t_1$. Since firm $I$ can raise $F(t_2)$ until this constraint is binding, we have $\Pi^E_2(t_1,t_2) = \Pi^{NA}_2(t_1)$, and hence,

$$F(t_2) = \int_{t_2}^{\infty} e^{-\delta t} \left( \pi^d(c,c) - \pi^d(\bar{c},c) \right) dt = \frac{\pi^d(c,c) - \pi^d(\bar{c},c)}{\delta} e^{-\delta t_2}.$$ 

Now, consider constraints (i) and (ii). Constraint (i) states that firm $I$ has to set $F(t_1)$ such that firm 1 prefers adopting at $t_1$ than adopting at $t_2$, simultaneously with firm 2. This implies that

$$F(t_1) \leq F(t_2) + \int_{t_1}^{t_2} e^{-\delta t} \left( \pi^d(c,c) - \pi^d(\bar{c},c) \right) dt. \tag{7}$$

Condition (ii) means that firm 2 should prefer adopting at $t_2$ than adopting at $t_1$, simultaneously with firm 1. It holds if

$$F(t_1) \geq F(t_2) + \int_{t_1}^{t_2} e^{-\delta t} \left( \pi^d(c,c) - \pi^d(\bar{c},c) \right) dt. \tag{8}$$

We assume that $\pi^d(c,c) - \pi^d(\bar{c},c) > \pi^d(c,c) - \pi^d(\bar{c},\bar{c})$,\(^9\) Firm $I$ can raise $F(t_1)$ such that condition (7) binds, and in this case condition (8) holds. Therefore, firm $I$’s profit writes

$$2 \int_{t_2}^{\infty} e^{-\delta t} \left( \pi^d(c,c) - \pi^d(\bar{c},c) \right) dt + \int_{t_1}^{t_2} e^{-\delta t} \left( \pi^d(c,c) - \pi^d(\bar{c},\bar{c}) \right) dt - A(t_1) - A(t_2).$$

The two first-order conditions write

$$-e^{-\delta t_1} \left[ \pi^d(c,\bar{c}) - \pi^d(\bar{c},\bar{c}) \right] - A'(t_1) = 0, \tag{9}$$

\(^9\)This is true, for example, in a model of Cournot competition.
and
\[-e^{-\delta t_2} \left[ 2 \left( \pi^d (\bar{c}, \bar{c}) - \pi^d (\bar{c}, \bar{c}) \right) - \left( \pi^d (c, c) - \pi^d (c, c) \right) - A' (t_2) \right] = 0. \tag{10} \]

As \( \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) > \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) \), we have \( 2 \left( \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) \right) - \left( \pi^d (c, c) - \pi^d (c, c) \right) < \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) < \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) \), and therefore, we have \( t_1^* < t_2^* \), where \( t_1^* \) and \( t_2^* \) denote the solutions of\( (9) \) and\( (10) \), respectively.

We can now state the following result.

**Proposition 3** Assume that the downstream market is a duopoly, that the technology market is monopolistic and that the two downstream firms can adopt the new technology. Compared to a competitive technology market, in equilibrium: (i) the leader adopts the new technology later, at its stand-alone date; (ii) the follower also adopts later.

**Proof.** (i) the first-order condition\( (9) \) corresponds to the stand-alone problem for firm 1; therefore firm 1 adopts later than with a competitive technology market. (ii) Since \( 2 \left( \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) \right) - \left( \pi^d (c, c) - \pi^d (c, c) \right) < \pi^d (c, c) - \pi^d (\bar{c}, \bar{c}) \), the follower adopts later than with a competitive technology market. □

This Proposition confirms the results of Proposition 2. With a monopolistic technology market, preemption does not occur, because it dissipates industry profits, which is not in the interest of the upstream monopoly.

Part (ii) of Proposition 3 shows that the second downstream firm also adopts the new technology later than with a competitive technology market. This is because the adoption of the follower creates a negative externality on the leader’s profit. For a given leader’s adoption date, the earlier the follower adopts the new technology, the lower the leader’s profit. With a competitive technology market, this externality does not affect the firms’ adoption dates, in particular because the follower’s adoption date does not depend on the leader’s. However, a monopolistic technology provider internalizes this externality and, as the Proposition shows,
delays the follower’s adoption to increase industry profits.

4 Imperfect competition in the upstream technology market

In this section, we still assume that the downstream market is a duopoly and we introduce potential competition in the upstream market, so as to mitigate the market power of the upstream monopoly. To that end, we assume that at the beginning of time (i.e., at date 0), outside firms start undertaking R&D to imitate the new technology.\footnote{Another possibility would be to assume that imitation starts when the new technology is introduced in the downstream market.} After a delay $\Delta > 0$, the imitators enter the upstream technology market, and it becomes perfectly competitive. We assume that the cost of the new technology for the imitators is the same as for firm $I$, that is, $C(t)$.

The following Proposition shows how the equilibrium (as described in Proposition 3) is affected.

**Proposition 4** Assume that at date $\Delta$, imitators enter the upstream technology market.

(i) If $\Delta > t^*_2$, then the equilibrium dates of adoption, $t^*_1$ and $t^*_2$, are unchanged.

(ii) If $\Delta < t^*_1$, then the leader adopts preemptively at date $\max\{\Delta, T^P\}$ and the follower adopts at date $t^*$.

(iii) If $\Delta \in [t^*_1, t^*_2]$, then the leader adopts at its stand-alone date and the follower adopts at date $\max\{\Delta, t^*\}$.

**Proof.** See Appendix D. ■

When the entry date of the imitators is sufficiently late, the equilibrium dates of adoption of the two downstream firms are unchanged. Similarly, if the entry date of the imitators is sufficiently early, the equilibrium dates of adoption correspond to the ones in the benchmark with a competitive technology market.
For intermediate values of the entry date of imitators, we find that the leader adopts at its stand-alone date. Therefore, even under the pressure of potential imitators, the upstream monopoly decides on an adoption date that maximizes the leader’s profit. Indeed, potential competition from imitators lowers the surplus that the upstream firm can extract from the downstream firms. However, the upstream firm still has incentives to maximize industry profits by implementing the appropriate adoption dates.

This result shows that our main result –market power in the upstream technology market annihilates preemption incentives– is still valid when the upstream monopoly faces potential competition.

5 Conclusion

Models of technological adoption in continuous time assume that the adoption cost is exogenous and decreasing over time because of increased efficiency of technology suppliers. This implicitly assumes perfect competition in the technology market, and leads in particular to the “rent dissipation” result of Fudenberg and Tirole (1985). A supplier with market power, however, could be able to capture a share downstream profits, and hence, internalize these profits when it sets the price for the new technology.

In this paper, we have proposed an adoption model where the upstream technology market is not perfectly competitive. When the downstream market is monopolistic, we have shown that the structure of the upstream market does not affect the adoption of the new technology. However, when the downstream market is a duopoly, it does. We find that when the upstream market is monopolistic, there is no preemptive race in the downstream market in equilibrium. The leader adopts later than when the upstream market is competitive. When the two downstream firms can adopt the new technology, the follower also adopts later. These delays are induced by the upstream monopoly, through a time-dependent pricing scheme.
References


Appendix

Appendix A: Proof of Lemma 1

We develop the proof for the non-drastic innovation case (the proof is similar for the drastic innovation case). We have

\[
\Pi_i(T) - \Pi_i^{NA}(T) = \int_T^\infty e^{-\delta t} \left[ \pi^d(\xi, \tau) - \pi^d(\tau, \xi) \right] dt - A'(T) = \frac{\pi^d(\xi, \tau) - \pi^d(\tau, \xi)}{\delta} e^{-\delta T} - A(T),
\]

which is a continuous function. We have \( \lim_{T \to \infty} \Pi_i(T) - \Pi_i^{NA}(T) = 0 \). Besides, from our assumptions, we have \( \Pi_i(0) - \Pi_i^{NA}(0) < 0 \), since \( \delta C(0) = m(\xi) \) and \( m(\xi) \geq \pi^d(\xi, \tau) - \pi^d(\tau, \xi) \).

Therefore, there is at least a date \( T^P \) such that \( \Pi_i(T) = \Pi_i^{NA}(T) \).

We now show that \( T^P \) is unique. If \( \Pi_i(T) - \Pi_i^{NA}(T) \) has an interior minimum or maximum, then the first-order condition is satisfied, and hence,

\[
\frac{d}{dT} \left( \Pi_i(T) - \Pi_i^{NA}(T) \right) = - \left( \pi^d(\xi, \tau) - \pi^d(\tau, \xi) \right) e^{-\delta T} - A'(T) = 0.
\]

The second-order condition then writes

\[
\frac{d^2}{dT^2} \left( \Pi_i(T) - \Pi_i^{NA}(T) \right) = \delta \left( \pi^d(\xi, \tau) - \pi^d(\tau, \xi) \right) e^{-\delta T} - A''(T).
\]

Using \( (\pi^d(\xi, \tau) - \pi^d(\tau, \xi)) e^{-\delta T} = -A'(T) \), the second-order condition can be rewritten

\[
\frac{d^2}{dT^2} \left( \Pi_i(T) - \Pi_i^{NA}(T) \right) = -\delta A'(T) - A''(T) = Z'(t) e^{-\delta T} < 0.
\]

Therefore, any optimum of \( \Pi_i(T) - \Pi_i^{NA}(T) \) is maximum. This shows that \( \Pi_i(T) - \Pi_i^{NA}(T) \) cuts the horizontal axis from below only once.
5.1 Appendix B: Proof of Lemma 2

The problem of the follower, firm $j$, can be written as

$$\max_{t_j \geq t_i} \frac{e^{-\delta t_j}}{\delta} \left( \pi^d(c, \xi) - \pi^d(\bar{\tau}, \xi) \right) - A(t_j).$$

The first-order condition writes

$$\pi^d(c, \xi) - \pi^d(\bar{\tau}, \xi) = -A'(t_j) e^{\delta t_j} = Z(t_j),$$

which implies that $t_j = t^* = Z^{-1} \left( \pi^d(c, \xi) - \pi^d(\bar{\tau}, \xi) \right)$, as $Z(\cdot)$ is a strictly decreasing function.

The second-order derivative at $t_j = t^*$ is

$$\left. \frac{\partial \Pi^F_i(t_i, t_j)}{\partial t_j^2} \right|_{t_j = t^*} = \delta \left( \pi^d(c, \xi) - \pi^d(\bar{\tau}, \xi) \right) e^{-\delta t_j} - A''(t_j)$$

$$= Z'(t^*) e^{-\delta t^*} < 0,$$

hence, the first-order condition defines a maximum.

The follower’s optimal adoption date is then $t^*$ if $t^* \geq t_i$, and $t_i$ otherwise.

5.2 Appendix C: Proof of Lemma 3

The proof is similar to the proof of Lemma 1. We have

$$\Pi^L_i(T, t^F(T)) - \Pi^F_i(T, t^F(T)) = \frac{\pi^d(c, \bar{\tau}) - \pi^d(\bar{\tau}, \xi)}{\delta} e^{-\delta T} - A(T),$$

which is a continuous function. To begin with, we have $\Pi^L_i(t^*, t^F(t^*)) - \Pi^F_i(t^*, t^F(t^*)) = 0$. Besides, from our assumptions, we have $\Pi^L_i(0, t^F(0)) - \Pi^F_i(0, t^F(0)) < 0$, since $\delta C(0) > \pi^m(\xi)$ implies that $\Pi^L_i(0, t^F(0)) < 0$ and $\Pi^F_i(0, t^F(0)) \geq 0$. Therefore, there is at least a date $T^P$ such that $\Pi^L_i(T, t^F(T)) - \Pi^F_i(T, t^F(T))$. 

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We now show that $T^P$ is unique. If $\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))$ has an interior minimum or maximum, then the first-order condition is satisfied, and hence,

$$\frac{d}{dT} (\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))) = -\left( \pi^d (c, \tau) - \pi^d (\bar{c}, \bar{\tau}) \right) e^{-\delta T} - A' (T) = 0.$$ 

The second-order condition then writes

$$\frac{d^2}{dT^2} (\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))) = \delta \left( \pi^d (c, \tau) - \pi^d (\bar{c}, \bar{\tau}) \right) e^{-\delta T} - A'' (T).$$

Using $\left( \pi^d (c, \tau) - \pi^d (\bar{c}, \bar{\tau}) \right) e^{-\delta T} = -A' (T)$, the second-order condition can be rewritten

$$\frac{d^2}{dT^2} (\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))) = -\delta A' (T) - A'' (T) = Z' (t) e^{-\delta T} < 0.$$

Therefore, any optimum of $\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))$ is maximum. This shows that $\Pi^L_i (T, t^F (T)) - \Pi^F_i (T, t^F (T))$ cuts the horizontal axis from below only once.

**Appendix D: Proof of Proposition 4**

The entry of imitators at date $\Delta$ creates an outside option for the downstream firms. However, since the value of this outside depends only on $\Delta$, it does not directly affect the choice of $t_1$ and $t_2$ by the upstream monopoly. What changes is that the upstream monopoly has to lower its prices to compensate the downstream firms for their more valuable outside option.

Given this reasoning, (i) If $\Delta > t^*_2$, then the equilibrium dates of adoption, $t^*_1$ and $t^*_2$, are unchanged; (ii) if $\Delta < t^*_1$, then the leader adopts preemptively at date $\max \{\Delta, T^P\}$ and the follower adopts at date $t^*$; (iii) if $\Delta \in [t^*_1, t^*_2]$, then the leader adopts at its stand-alone date and the follower adopts at date $\max \{\Delta, t^*\}$. 

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