THE DIFFUSION OF NEW TECHNOLOGY: ADOPTION SUBSIDIES, SPILLOVERS, AND TRANSACTION COSTS

by

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Abstract: We establish the relation between optimal subsidy rates and spillovers from the sequential adoption of a new technology; we find that they evolve in the same direction over time. We show that spillovers, hence the subsidy rates, need not be monotonic. We show that when subsidy rates are increasing, their growth rate has to be paced by the growth rate of the present cost of the adoption of the new technology. We also show that increasing subsidies rates cannot produce the desired effect of accelerating adoption if the social cost of public funds is relatively high; hence first-best subsidy adoptions are not always possible.

Key words: Adoption subsidies, Adoption spillovers, Technology adoption, Technology diffusion, Transaction costs.

JEL Classification: O31, O33, O38

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1. Introduction

A new technology goes through two principal stages; the invention stage and the innovation stage. The invention stage is driven by firms' decision to undertake research and development efforts, the economic literature is abound with studies that attempt to understand and explain firms' decisions to undertake R&D activities. R&D effort however, bears fruits only when research output is incorporated into the production process. A new technology is incorporated into the production process (innovation stage) only when tangible gains from its use are expected or have been demonstrated elsewhere. In some situation, it is possible that between the invention stage and the innovation stage additional efforts are needed to accelerate the diffusion of the new technology. For instance, in situations where inputs are particularly scarce, as is the case with water and energy for example, the regulator may be inclined to encourage the early adoption of a new input-saving technology using subsidies, where the regulator underwrites part of the cost that each firm incurs upon the adoption of the new technology.

The diffusion of a new technology was studies by Reinganum (1981a,b), Fudenberg and Tirole (1985), and Quirmbach (1986) among others. Hoppe (2002) gives an extensive survey of the literature about the timing of new technology adoption, she distinguishes between: (i) certain vs. uncertain value and availability of the new technology, and (ii) between strategic vs. non strategic adoption of the new technology. Reinganum (1981a,b) shows that although identical and fully informed, firms adopt a new technology sequentially, the underlying assumption of the model is precommitment to adopt following a given sequence. Fudenberg and Tirole (1985) study the adoption of new technology and outline the importance of the threat of preemption as a rent-equalizing factor in games of timing. They show that when preemption is possible then in the case of a symmetric duopoly, payoffs are equal in equilibrium and adoption is simultaneous, however in an oligopoly that must not be the case.[1] Hendricks (1992) studies the effect of uncertainty about the gains from the new technology and concludes that qualitatively the equilibrium with uncertainty and without adoption precommitment is the same as the equilibrium without uncertainty but with commitment to adopt.

In all the studies mentioned above and those covered by Hoppe (2002), adoption subsidies where not considered. The properties of subsidies that promote the adoption of the new technology, the relation between adoption subsidies and the spillovers from adoption, or the effect of the social cost of public funds on adoption subsidies remain largely unresearched. In this paper we setup a fairly general model of timing of new technology adoption and adoption subsidies where uncertainty is ruled out and precommitment to adoption is assumed.[2] We establish the relation between subsidy rates and spillovers from the sequential adoption of the new technology and we find that they evolve in the same direction over time. The intuition suggests that subsidy rates should be decreasing over time when the cost of adopting the new technology decreases over time as shown in Khraief (1997).[3] First, we show that contrary to the intuition, spillovers from adoption hence subsidy rates are not always monotonic. Then we show that when subsidy rates are increasing, their growth rate has to be paced by the growth rate of the present cost of the adoption of the new technology. Last, we show that increasing subsidies

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[1] In Fudenberg and Tirole (1985) preemption is considered possible when information lags are short, so firms can observe and preempt their rivals' actions.
[2] Precommitment is equivalent to infinite information lags.
[3] Khraief (1997) establishes that in the case of a duopoly with linear demand and constant marginal cost the adoption subsidy is decreasing when the new technology reduces the marginal cost.

cannot produce the desired effect of accelerating adoption if the social cost of public funds or transaction costs are relatively high. In which case, the regulator should offer only second-best subsidy rates or abstain from subsidizing the adoption of the new technology if it implies an increase in subsidy rate over time. This last point is particularly important because in many developing countries where transaction costs are high, adoption subsidies are being used indiscriminately to promote new and efficient technologies.

Stoneman and David (1986), develop a model with adoption subsidies to show that subsidies may not always increase welfare and that it depends on the market structure in the supply of the new technology, however in their model Stoneman and David did not allow for the subsidy to change over time and its level is exogenous to the model while in our model the subsidy rate is endogenously determined for each period where adoption occurs, and is function of the gains from adoption. Jaffe and Stavins (1994) present compelling arguments in favor of the use of adoption subsidies, such as the information value from the use of the new technology by some firms and its effects on spreading the use to other firms. Also, the use of adoption subsidies can be motivated by the existence of free-rider problems that reduce R&D efforts, the regulator's support through adoption subsidies to reduce the cost of adoption may be necessary to circumvent that. The diffusion of the new technology can in principal be promoted through command and control instruments such as technology standards, those can be justified in the presence of negative externalities such as pollution, however in addition to the possibility of choosing an unambitious or infeasible standards that approach is socially inefficient and tends to reduce incentives to innovate (Jaffe and Stavins, 1995).

The outline of the paper is as follows. We introduce the general model and its assumptions then we discuss the properties of the adoption subsidies in the duopoly case that we generalize to many firms, we discuss the feasibility of increasing subsidy rates, and then conclude.

2. The model

Consider an industry where *N* firms produce a homogenous good using technology $v \in \{0,1\}$, the old technology denoted by 0, or the new technology denoted by 1. The new technology is made available at period zero and has the advantage of reducing the marginal cost of production. If the new technology is adopted at period *t* then its cost is $k(t)$, with *r* being the discount rate, its present value cost is $L(t) = k(t)e^{-rt}$. It is assumed that the cost of the new technology decreases with time, $\dot{k}(t) < 0$, but never reaches zero, $\lim_{t \to \infty} k(t) > 0$.[4]

When $n \leq N$ firms adopt the new technology and a firm uses technology *v*, then its profit at every period is π_n^v with the proviso that π_0^1 and π_N^0 do not exist. We assume that;

Assumption 1. *Firms realize positive profits,* $\pi_n^v > 0; \forall v, n$.

Assumption 2. *The adoption of the new technology is always more profitable than the non adoption and that one firm's profit decreasing as more firms adopt the new technology,* $\pi_n^1 > \pi_{n'}^1 > \pi_0^0 > \pi_n^0; \forall n' \geq n$.

One can setup a payoff matrix of the decision to adopt the new technology in static and find that the Nash equilibrium is that all firms adopt the new technology. However the introduction of dynamics leads to a different outcome. In the case of *N* firms, if a firm is the n^{th} to adopt the new technology, then it chooses the optimal period T_n of adoption by maximizing;

[4] We assume away incremental adoption of new technologies addressed by Lissoni (2005).

$$V\left(T_n\right)=\int_0^{T_1}\pi_0^0 e^{-rt}dt+\int_{T_1}^{T_2}\pi_1^0 e^{-rt}dt+\cdots+\int_{T_n}^{T_{n+1}}\pi_n^1 e^{-rt}dt+\cdots+\int_{T_N}^{\infty}\pi_N^1 e^{-rt}dt-L\left(T_n\right). \quad (1)$$

In the case of a duopoly, Reinganum (1981a) shows that there are two symmetric Nash equilibiria and conjectures that in an oligopoly there are $N!$ pure symmetric Nash equilibria; one equilibrium for each possible sequence of the firms' adoption of the new technology. Reinganum (1981a,b) shows also that simultaneous adoption of the new technology is not an equilibrium, a diffusion process takes place although the firms are identical and operating in a full information environment, including in the case of an oligopolistic market (Reinganum, 1981b).[5] So in the remainder of this paper the following assumption holds.

Assumption 3. *Firms adopt the new technology sequentially*.[6]

3. Technology adoption subsidies

When a firm adopts the new technology its marginal cost decreases, hence its output increases. At the aggregate level, the sequence of total outputs $\{Q_n\}$ is positive increasing and the sequence of consumers' surpluses $\{S_n\}$ is positive increasing. We define $\{w_n\}$ as being the sequence of social welfares – the sum of consumers' surplus and firms' profits. The aforementioned sequences are all assumed bounded above, hence convergent. Typically $\{Q_n\}$, $\{S_n\}$, and $\{w_n\}$ converge to their perfect competition levels as $n \to N$ and $N \to \infty$.

For a firm to be the n^{th} to adopt the new technology at period T_n we define $s_n \equiv s(T_n)$, $L_n \equiv L(T_n)$, and $k_n \equiv k(T_n)$. With $\lambda > 0$ the social cost of public funds (can also be thought off

[5] Reinganum (1981b) attributes the diffusion process to "purely strategic behavior" while Quirmbach (1986) attributes it to decreasing incremental benefits and adoption costs for late adopters.
[6] Fudenberg and Tirole (1985) noted that implicitly it is assumed that there is a precommitment to adopt and that information lags are infinite.

as transaction cost), the regulator maximizes the following program to determine the optimal subsidy rates $\{s_n\}$,

$$\max_{\{s_n\}} W(s_1,\cdots,s_N) = \int_0^{T_1} w_0 e^{-rt}dt + \int_{T_1}^{T_2} w_1 e^{-rt}dt + \cdots + \int_{T_n}^{T_{n+1}} w_n e^{-rt}dt + \cdots + \int_{T_N}^{\infty} w_N e^{-rt}dt \\ -\sum_n (1-s_n)L_n - (1+\lambda)\sum_n s_n L_n \tag{2}$$

s.t.

$$T_n \equiv \arg\max_{T_n} V(T_n) + s_n L_n; \qquad \forall n \le N \tag{3}$$

To determine s_n, the first-order conditions are:

$$\begin{cases} -r\dfrac{dT_n}{ds_n}\left[(w_{n-1}-w_n)e^{-rT_n} - \dot{L}_n - \lambda\left(\dot{s}_n L_n + s_n \dot{L}_n\right)\right] = 0 \\ \left(\pi_{n-1}^0 - \pi_n^1\right)e^{-rT_n} + \dot{s}_n L_n - (1-s_n)\dot{L}_n = 0 \end{cases}, \tag{4}$$

In the above expression, the adoption process is represented mathematically as a continuous time event but in reality adoption is a discrete time event. When solved first for L_n and then for s_n, the first-order conditions give the optimal subsidy rate for the n^{th} adopter:

$$s_n = \frac{(w_n - w_{n-1}) - \left(\pi_n^1 - \pi_{n-1}^0\right)}{(w_n - w_{n-1}) + \lambda\left(\pi_n^1 - \pi_{n-1}^0\right)}, \tag{5}$$

From the above expressions of subsidy rates, one notices that they decrease as the social cost of public funds increases, which is usually the case of countries with heavy bureaucracies, and corruption. As we will be discuss later, adoption subsidies cannot be offered at all levels of λ, but if the cost of public funds is zero, $\lambda = 0$, then the subsidy rates depend directly on spillovers from the sequential adoption of the new technology. Spillovers refer to the gains to the rest of the economy when a firm adopts the new technology. We define the spillover ratio by:

$$\beta_n = \frac{S_n - S_{n-1} + (n-1)\left(\pi_n^1 - \pi_{n-1}^1\right) + (N-n)\left(\pi_n^0 - \pi_{n-1}^0\right)}{\pi_n^1 - \pi_{n-1}^0}, \tag{6}$$

then with $\lambda = 0$ the subsidy rate becomes,

$$s_n = \frac{\beta_n}{1+\beta_n}. \tag{7}$$

Using (5), comparing s_n and s_{n-1} is equivalent to comparing $\frac{\beta_n}{1+\beta_n}$ and $\frac{\beta_{n-1}}{1+\beta_{n-1}}$, therefore studying the direction of the sequence $\{s_n\}$, in (5) or in (7), is equivalent to studying the direction of the sequence $\{\beta_n\}$, as they evolve in the same direction. By definition $0 \le s_n < 1$, therefore the spillover from the adoption is positive $\beta_n > 0$, notice that if the subsidy rate is equal to one, all the firms adopt the new technology at period zero since all the costs are paid for by the regulator. We summarize those finding in the following proposition.

Proposition 1: *The welfare maximizing subsidy from problem (2)-(3) is given by (5). When $\lambda = 0$ then the subsidy rate depends directly on the spillover ratio β_n, further when $\lambda > 0$, the subsidy rate s_n and the spillover ratio β_n evolve in the same direction.*

3.1. Case where *N*=2

We consider a duopoly, to show that the optimal subsidy rate can be decreasing as well as increasing. With $\{P_n\}$ the nonincreasing sequence of prices, let $\varepsilon_n = -\frac{P_n - P_{n-1}}{Q_n - Q_{n-1}}$, then the following four lemmas and corollary show that generally the subsidy rate cannot be monotonic.

Lemma 1. *If* $\varepsilon_1 \to 0$ *and* $\varepsilon_2 > 0$, *then the subsidy rate to the early adopter is lower then the subsidy rate to the late adopter, i.e.* $s_1 < s_2$.

Proof. If $\varepsilon_1 \to 0$ then $S_1 \to S_0$, competition between the two firms is akin to perfect competition because any change in one firms output does not induce a change in the price of the good when the aggregate output is between Q_0 and Q_1. If a change in a firm's output does not affect the output price, then the output of the other firm is not affected and its profit is unchanged regardless if the first firm adopts the new technology or not, $\pi_1^0 \to \pi_0^0$. Therefore $\beta_1 \to 0$ and $\beta_2 > 0$, hence $s_1 < s_2$. □

Lemma 2. *If* $\varepsilon_1 > 0$ *and* $\varepsilon_2 \to 0$, *then the subsidy rate to the early adopter is greater then the subsidy rate to the late adopter, i.e.* $s_1 > s_2$.

Proof. If $\varepsilon_2 \to \infty$ then $S_2 \to S_1$, after the first firm adopts the new technology, competition between the two firms is akin to perfect competition because the change in the later adopter output does not induce a change in the price of the good when the aggregate output is between Q_1 and Q_2. This implies that $\pi_2^1 \to \pi_1^1$, hence $\beta_1 > 0$, $\beta_2 \to 0$, and $s_1 > s_2$. □

Lemma 3. *If* $\varepsilon_1 \to 0$ *and* $\varepsilon_2 \to 0$ *then* $s_1 \to s_2$.

Proof. If $\varepsilon_1 \to 0$ and $\varepsilon_2 \to 0$ then $S_1 \to S_0$ and $S_2 \to S_1$, although the decision of the firm to adopt the new technology reduces their marginal costs, thereby increases their outputs, the price does not change. It is as if both firms are operating in a perfectly competitive market.

In terms of relations between the various profits, this implies that $\pi_1^0 \to \pi_0^0$ and $\pi_2^1 \to \pi_1^1$. Therefore $\beta_1 \to 0$ and $\beta_2 \to 0$, hence $s_1 \to s_2$. □

Lemma 4. *If* $\varepsilon_1 \not\to 0$, $\varepsilon_2 \not\to 0$, *then:*

i) $s_1 > s_2$ *if* $S_1 - S_0 > \pi_1^1 - \pi_1^0 > S_2 - S_1$ *and vice-versa if* $S_1 - S_0 < \pi_1^1 - \pi_1^0 < S_2 - S_1$,

ii) $s_1 < s_2$ *if* $S_2 - S_1 > S_1 - S_0 > \pi_1^1 - \pi_1^0$ *and vice-versa if* $S_2 - S_1 < S_1 - S_0 < \pi_1^1 - \pi_1^0$,

iii) It is not conclusive if $S_1 - S_0 > S_2 - S_1 > \pi_1^1 - \pi_1^0$ *or* $S_1 - S_0 < S_2 - S_1 < \pi_1^1 - \pi_1^0$.

Proof. As stated earlier comparing s_1 and s_2 is equivalent to comparing β_1 and β_2, which after simplifications and rearrangement implies comparing $(\pi_2^1 - \pi_1^0)\left[(S_1 - S_0) - (\pi_1^1 - \pi_1^0)\right]$ and $(\pi_1^1 - \pi_1^0)\left[(S_2 - S_1) - (\pi_1^1 - \pi_1^0)\right]$. With assumption 2, it is straightforward to check that the above conditions are fulfilled and their conclusions hold. □

Corollary 1. In Lemma 4, if the first condition applies then we either have $\beta_1 > 1 > \beta_2$ or $\beta_1 < 1 < \beta_2$, but if the second condition applies then we either have $\beta_2 > \beta_1 > 1$ or $\beta_1 > \beta_2 > 1$. If the third condition applies we either have $(\beta_1, \beta_2) < (1,1)$ or $(\beta_1, \beta_2) > (1,1)$, but no further ranking of β_1 and β_2 is possible without additional details about the functional forms.

3.2. Case where *N*>2

We show that in general the spillover ratio is not monotonic, for that we need to establish the behavior of the sequences $\{S_n - S_{n-1}\}$, $\{\pi_n^1 - \pi_{n-1}^1\}$, $\{\pi_n^0 - \pi_{n-1}^0\}$, and $\{\pi_n^1 - \pi_{n-1}^0\}$ in the following lemmas.

Lemma 5. The sequence $\{S_n - S_{n-1}\}$ is positive decreasing.

Proof. Consider the sequence $\{S_n - S_{n-1}\}$, then the series $\sum_{n=1}^{N} S_n - S_{n-1} = S_N - S_0 < S_N$ is convergent, because $\{S_n\}$ is bounded, therefore by the infinite series theorem $\lim_{\substack{n \to N \\ N \to \infty}} S_n - S_{n-1} = 0$. Since $\{S_n\}$ is a positive increasing sequence then the sequence $\{S_n - S_{n-1}\}$ is positive decreasing. □

Lemma 6. The sequence $\{\pi_n^1 - \pi_{n-1}^1\}$ is negative increasing.

Proof. Consider the sequence $\{\pi_n^1 - \pi_{n-1}^1\}$, then the series $\sum_{n=1}^{N} \pi_n^1 - \pi_{n-1}^1 = \pi_N^1 - \pi_0^1 < \pi_N^1$ is convergent, because $\{\pi_n^1\}$ is bounded, the infinite series theorem implies that $\lim_{\substack{n \to N \\ N \to \infty}} \pi_n^1 - \pi_{n-1}^1 = 0$. Since $\{\pi_n^1\}$ is a positive decreasing sequence then the sequence $\{\pi_n^1 - \pi_{n-1}^1\}$ is negative increasing. □

Lemma 7. The sequence $\{\pi_n^0 - \pi_{n-1}^0\}$ is negative increasing.

Proof. Consider the sequence $\{\pi_n^0 - \pi_{n-1}^0\}$, then the series $\sum_{n=1}^{N} \pi_n^0 - \pi_{n-1}^0 = \pi_N^0 - \pi_0^0 < \pi_N^0$ is convergent, because $\{\pi_n^0\}$ is bounded, the infinite series theorem implies that $\lim_{\substack{n \to N \\ N \to \infty}} \pi_n^0 - \pi_{n-1}^0 = 0$. Since $\{\pi_n^0\}$ is a positive decreasing sequence then the sequence $\{\pi_n^0 - \pi_{n-1}^0\}$ is negative increasing. □

Lemma 8. The sequence $\left\{\pi_n^1 - \pi_{n-1}^0\right\}$ is positive, decreasing and convergent.

Proof. By assumption 2, we have $\pi_n^1 - \pi_{n-1}^0 > 0$. The sequence $\left\{\pi_n^1 - \pi_{n-1}^0\right\}$ is therefore positive, decreasing and convergent because as the number of firms who adopt the new technology increases the gains from the adoption of the new technology shrink, this implies that $\left\{\dfrac{1}{\pi_n^1 - \pi_{n-1}^0}\right\}$ is increasing. □

Proposition 2. *The sequence of spillovers* $\left\{\beta_n\right\}$ *converges to zero but is not monotonic, therefore the subsidy rates sequence* $\left\{s_n\right\}$ *is also not monotonic and converges to zero.*

Proof. Let $\Delta_n = S_n - S_{n-1} + (n-1)\left(\pi_n^1 - \pi_{n-1}^1\right) + (N-n)\left(\pi_n^0 - \pi_{n-1}^0\right)$, then from the above lemmas we have $\sum_{n=1}^{N} \Delta_n < S_N + (N-1)\pi_N^1$ hence $\lim_{\substack{n\to N\\ N\to\infty}} \Delta_n = 0$. This implies that $\lim_{\substack{n\to N\\ N\to\infty}} \beta_n = 0$. Lemmas 5 to 7 show that $\left\{\Delta_n\right\}$ is not monotonic, therefore $\left\{\beta_n\right\}$ and $\left\{s_n\right\}$ are also not monotonic. □

4. Feasibility of Increasing Subsidies

We showed above that the optimal subsidy rate is not monotonic but it converges to zero. The adoption of the new technology occurs at discrete time periods; the evolution of the subsidy rate over time can either start by increasing or start by decreasing. In (5) it is easy to check that we always have $s_n < 1$, so even if the subsidy rate starts by decreasing, its initial value is not one because as mentioned earlier a subsidy rate equal to 1 induces all the firms to simultaneously adopt the new technology as soon as it is made available.

Technology adoption subsidies are designed to speed up the diffusion process, however as we show below if the subsidy rate is increasing then it needs to be paced and an increasing optimal subsidy rate is viable only for a class of countries having relatively low transaction costs and social cost of public funds. For a given firm, the first-order conditions for determining the adoption dates with and without subsidy are:

$$\begin{cases} \left(\pi_{n-1}^{0} - \pi_{n}^{1}\right) e^{-r\hat{T}} - \dot{L} = 0 \\ \left(\pi_{n-1}^{0} - \pi_{n}^{1}\right) e^{-r\hat{\hat{T}}} + \dot{s}L - \left(1-s\right)\dot{L} = 0 \end{cases}, \tag{8}$$

The first-order conditions (8) imply that:

$$\begin{cases} \pi_{n}^{1} - \pi_{n-1}^{0} = rk(\hat{T}) - \dot{k}(\hat{T}) \\ \pi_{n}^{1} - \pi_{n-1}^{0} = \dot{s}(\hat{\hat{T}})k(\hat{\hat{T}}) + \left(1 - s(\hat{\hat{T}})\right)\left(rk(\hat{\hat{T}}) - \dot{k}(\hat{\hat{T}})\right) \end{cases}, \tag{9}$$

In figure 1, we assume that $\dot{s}k + \left(1-s\right)\left(rk - \dot{k}\right) < rk - \dot{k}$, in which case the firms would adopt the new technology at an earlier period than without subsidies. In case the subsidy rate decreases over time, $\dot{s} < 0$, then there are no perverse effects to the subsidy. But if subsidy rate increases over time, $\dot{s} > 0$, then for the subsidy to encourage earlier adoption, the growth rate of the subsidy rate must be paced by the growth rate of the present cost of the adoption of the new technology, $\frac{\dot{s}}{s} < r - \frac{\dot{k}}{k}$.

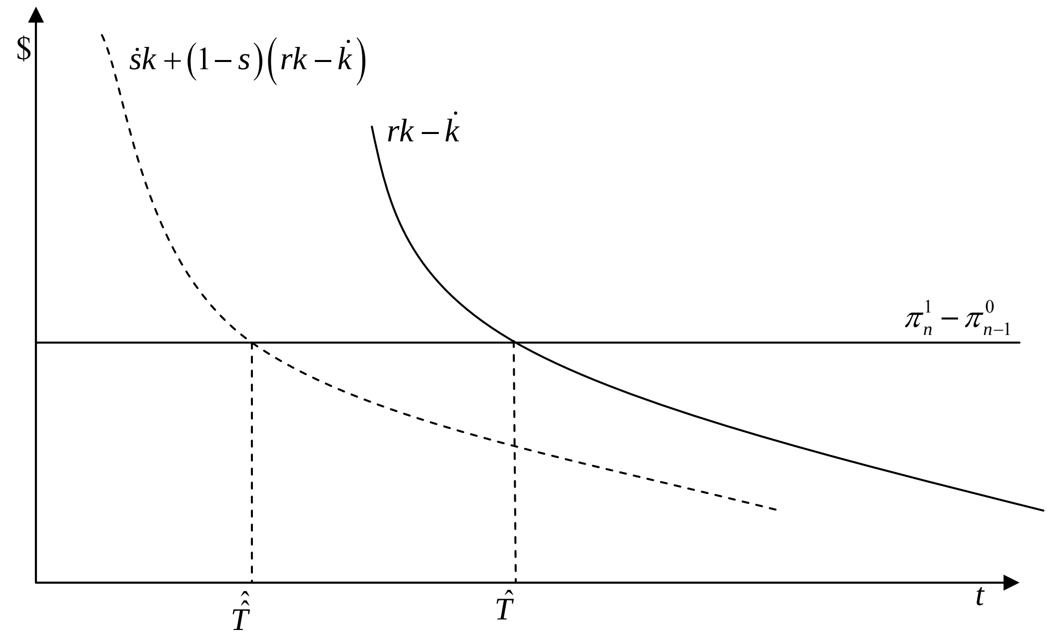

Figure 1. Effect of subsidies on the timing of adoption

We now show that when the subsidy rate is increasing the condition $\frac{\dot{s}}{s}<r-\frac{\dot{k}}{k}$ can only be met by a class of countries whose social cost of public funds does not exceed a determined level, beyond which a first-best optimal adoption subsidy should not be offered because it discourages and hence delays adoption. Let $\Delta w_n = w_n - w_{n-1}$ and $\Delta\pi_n = \pi_n^1 - \pi_{n-1}^0$, then using the discrete time version of $\frac{\dot{s}}{s}<r-\frac{\dot{k}}{k}$, one can show that only countries with $\lambda \le \lambda_n$, where

$$\lambda_n = \frac{\Delta\pi_n \Delta w_{n-1} - \alpha_n \Delta w_n \Delta w_{n-1} - \Delta w_n \Delta\pi_{n-1}(1-\alpha_n)}{\Delta\pi_{n-1}\Delta w_n + \alpha_n \Delta\pi_n \Delta\pi_{n-1} - \Delta w_{n-1}\Delta\pi_n(1+\alpha_n)} \qquad ;\alpha_n = r - \left(\frac{k_n}{k_{n-1}} - 1\right), \tag{10}$$

should offer optimal subsidy rates to all adopters of the new technology.

The implication of this is that for some countries, if $s_n > s_{n-1}$ but the condition $\lambda \le \lambda_n$ is not met, an optimal subsidy rate is not possible at period T_n, but a second-best subsidy rate such that $s' \le s_{n-1}$ could be offered. In fact, in that case even without a subsidy the firm would still adopt the new technology at period $\hat{T}_n \leq T_n$. If $\lambda > \liminf_{\substack{n \to N \\ N \to \infty}} \lambda_n$ the regulators offers only nonincreasing subsidy rates to all adopters, some of the offered subsidy rates are not optimal. We summarize the results of the discussion in the following proposition.

Proposition 3: *When adoption subsidy rates are decreasing the incentive to accelerate the adoption of a new technology is effective. But for increasing subsidy rates to be effective the following conditions must be met* $\frac{\dot{s}}{s} < r - \frac{\dot{k}}{k}$ *such that* $\lambda > \lambda_n$. *If* $\lambda > \liminf_{\substack{n \to N \\ N \to \infty}} \lambda_n$, *then adopters of the new technology are offered decreasing subsidy rates that are not always optimal.*

5. Conclusion

Using a general model of technology adoption we looked into the optimal timing of new technology adoption by firms in the presence of adoption subsides. Adoption subsidies are a commonly used instrument to promote R&D effort and the use new technology. We have established the link between optimal adoption subsidies and spillovers from the sequential adoption of the new technology. The intuition suggests that the subsidy rates should be decreasing because the adoption cost is decreasing over time; contrary to the intuition we showed that in general spillovers and adoption subsidy are not monotonic and that when subsidy rates are increasing careful attention must be paid to their growth rate and to the level of the social cost of public funds or transaction otherwise increasing subsidy rates may produce the undesirable effect of slowing down the adoption of the new technology.

In this paper it is assumed that all decisions are made under certainty, an obvious extension of the above model would be to include uncertainty about the gains from the new technology. This would affect the spillovers from adoption and adoption subsidy. Another possible extension would be to allow for the possibility of the appearance of a second new technology after the first new technology is made available, this would alter the gains from adoption and allow for the possibility of second mover's advantage that might lead to a qualitatively different outcome as far as subsidy and spillovers are concerned. One would expect that delays in the adoption of the first new technology appear and possibly put to a halt the adoption of the first technology. This in some ways is similar to the decision to purchase a personal computer, there is always the question whether one should buy now or maybe wait for a price drop or a new model to enter the market.

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