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Plant Breeders' Rights, Patents and Incentives to Innovate

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Abstract

Innovations on plant varieties can be protected by patents or Plant Breeders' Rights (PBRs). Although these methods of protection have similarities, they also have major differences. With the PBR regime, farmers are allowed to save part of their harvest to replant during the next period ("farmers' exemption"). To comply with international regulation, they must pay a tax to seed producers for the loss incurred due to this exemption. We analyze the impact of this exemption and its associated tax on seed prices and on the incentives to innovate in a monopoly setting. We find that with only a PBR regime, a relatively high tax level is necessary to eliminate self-production. If both patent and PBR regimes coexist, farmers might still self-produce if the seed innovation is protected with a PBR. Our findings suggest that the coexistence of the two regimes does not fully prevent self-production. Nevertheless, it boosts the research investment which is a non-monotonic function of the tax. The seed producer might over or under invest compared to what is socially optimal. Moreover, incentives to innovate are the strongest, either with a patent regime or with a PBR regime for which a high tax prevents seed saving. In terms of welfare, having both systems has ambiguous effects.

Keywords: Intellectual Property Rights, Plant Breeders' Rights, Seed Saving

JEL classifications: D23, K11, L12, Q12

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1 Introduction

Before the nineteenth century, varietal creations were obtained by conventional plant breeding: farmers would save part of their harvest (usually the best looking seeds) to plant for the next year. Nowadays, private companies (breeders or seed producers such as Monsanto or Pioneer) invest in Research and Development (R&D) to develop new varieties of crops that provide higher yields for farmers or lower environmental threats (e.g., reduce pest or vegetable diseases).

Because of the self-reproduction nature of crops, the output of crop research is non-excludable. If it is not explicitly forbidden,[1] farmers can save part of their harvest to self-produce during the next period as seed traits remain unchanged after several harvesting periods. Therefore, seed saving has an impact on pricing strategies and incentives to innovate of seed producers.

As farmers can save seed for the next period, seed varieties can be seen as durable goods (Coase, 1972; Bulow, 1982; Waldman, 2003). A producer can make the seed durable by choosing prices such that farmers buy the seed once and self-produce in the next periods. On the other hand, the seed producer can also choose prices such that farmers buy during each period (Ambec et al., 2008). Thus, depending on the pricing strategy, seeds are durable goods or not.

As seed saving decreases the seed producer's innovation appropriation, his incentive to invest in R&D can be altered. To address this "public" good issue, a certain level of appropriation is needed for private firms to innovate. Without Intellectual Property Rights (IPRs) that allow to establish the necessary appropriation for the private creation (Scotchmer, 2004), there is a lack of private incentives to innovate. IPRs provide a temporary monopoly power to innovators which leads to a possible static welfare loss necessary from a dynamic perspective.[2]

Once a seed producer has developed a new crop variety, he can protect his innovation[3] with a patent or a Plant Breeders' Right (PBR).[4] Many countries (Argentina, Canada, Germany, UK, France)[5] do not allow seed innovators to patent their innovations and only PBRs can be used.

[1]Through a contract or because the crop is sterile due, for instance, to genetic modification.

[2]For issues related to the introduction of IPRs see, for instance, Menell and Scotchmer, 2007.

[3]The agreement on Trade-Related aspect of Intellectual Property Rights (TRIPS) allows protecting innovation on living organisms for members of World Trade Organization (WTO).

[4]The PBR (also called Plant Variety Right, PVR) system, is a *sui-generis* system, which means that it is a unique system for living organisms.

[5]In the European Union, seeds and plants are not patentable; they can only be protected with PBRs. Directives 2100/94 and 98/44 that can be found, respectively, at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994R2100:EN:HTML and http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&numdoc=31998L0044&model=guichett&lg=en, last accessed March 2014.

In other countries (U.S., Japan, New Zealand and Australia),[6] both patent and PBR systems coexist and firms protect their plant innovations with both of them.[7] These two types of property rights have similarities but also major differences.

The main criteria for an innovation to be granted a patent are novelty and non-obviousness. A patent involves exclusive rights to make, use, sell, and distribute the invention. In the U.S. some plants (asexual species) are patentable since 1930 under the Plant Patent Act (PPA), while for other plants, an inventor can obtain a PBR under the Plant Variety Protection Act (PVPA) since 1970. Moreover, two decisions of the supreme court in 1980[8] and 2001[9] enable seed producers to patent a new variety (asexual or sexual) with a utility patent.

The PBR system was established by the International Union for the Protection of New Varieties of Plants (UPOV). In 2014, 72 countries are UPOV members and they use a PBR regime for their seed variety innovations.[10] The main requirements for PBRs are novelty and Distinction, Uniformity and Stability (DUS) test. Even though a PBR involves exclusive rights similar to those of a patent, there are two notable exemptions: private research with commercial purposes and seed saving.

The first exemption, called "research exemption," allows another producer to use proprietary seeds to create and commercialize a new variety without any agreement or licence on the first varieties. This is unlike the patent system, in which a patentholder can prevent a competitor to enter the market or can monopolize part of the new seed market with a licence.

The second exemption, called "farmers' exemption," allows a farmer to save part of his harvest to sow for the next period, even if the variety is the property of a seed producer. Seed producers can reduce the attractiveness of self-production by producing hybrid seeds as hybrid seed saving involves a very high yield loss. However, hybrid seeds are not yet well-developed for some species such as wheat. As a result, between 40 to 70% of wheat seeds come from seed saving worldwide (see Table 1, Curtis and Nilsson, 2012).

In countries members of UPOV, to comply with its most recent version, UPOV-91, self-

[6]They are called 'utility patents' in the U.S. and Japan and 'standard patents' in Australia.

[7]For instance, in 2013, Monsanto owned 427 U.S. patents and 69 Plant Variety Protection Act Certificates. Data are from the USPTO and USDA websites.

[8]Chakrabarty case on patenting micro-organisms. See, for instance, `http://caselaw.lp.findlaw.com/cgi-bin/getcase.pl?court=us&vol=447&invol=303`, last accessed March 2014.

[9]Pioneer versus JEM Ag Supply case `http://caselaw.lp.findlaw.com/scripts/getcase.pl?court=US&vol=000&invol=99-1996`, last accessed March 2014).

[10]Some non-UPOV member countries such as India have created similar regimes.

producing farmers must compensate seed producers for the incurred loss; they must pay a royalty on Farm Saved Seed (FSS). In table 1, we summarize the different methods of compensation depending on the countries as well as the reported percentage of self-production mostly for wheat.[11]

	PBR/Patent	**Self-Production**	**Royalty or tax**
Australia	both	90% (small grain)	Royalty
U.S.	both	66% (wheat)	–
Argentina	PBR	40% (wheat)	Royalty
Canada	PBR	80% (wheat)	Soon
Germany	PBR	57% (cereals)	Royalty
U.K.	PBR	42%	Royalty
France	PBR	49% (wheat)	Tax

Table 1: IPRs, self-production and Royalty for different countries

Because of these major exemptions, the PBR system can be seen as weaker than the patent system. It is also cheaper to obtain a PBR than a patent (Wright et al., 2007).

In a context similar to the European Union, where only PBRs are allowed, we are wondering what will be the impact of the introduction of the patent regime? In other words, how will the European system be affected by allowing seed producers to patent their innovations? How will the introduction of the patent system affect the protection choice and the incentive to innovate? What will be the impact on the social welfare?

We also investigate the reasons for a seed producer to use both IPRs in a system similar to the U.S. In other words, why does Monsanto have a mix of patents and PBRs? This gives rise to policy questions: should European countries allow seed producers to patent their seed innovations? What policy tools can be used to provide incentives to innovate?

PBRs have been extensively studied in the economic literature.[12] Recent empirical contributions find a small positive impact of PBRs on the agricultural productivity growth (Naseem et

[11]For instance, in France, an inter-professional agreement established in 2001 between farmers and seed companies has led to the creation of a tax paid by a farmer when he sells his output. If he buys the seed from the seed producer (and thus does not self-produce), he gets the tax refunded. See JORF 173, on page 12224 on http://www.legifrance.gouv.fr/ (in French).

[12]See Wright et al. (2007) for an overview about agricultural innovations.

al., 2005; Carew et al. 2009) while others find that only a few PBRs are valuable (Srinivasan, 2012). This latter finding is consistent with results about the value of patents in the patent literature (Schankerman and Pakes, 1986).

It is also not clear who benefits the most from PBRs. According to Moschini et al. (2000), innovators are those who benefit the most, while others contributions find that farmers might actually benefit from these innovations (Falck-Sepeda et al., 2000; Qaim and Traxler, 2005).

The impact of the two major exemptions of the PBR system has also been studied. In a sequential setting, Moschini and Yerokhin (2008) show that a PBR with the research exemption can be preferred to a patent if research costs are low. However, the research exemption will tend to decrease the incentive to innovate of the first innovators (Nagaoka and Aoki, 2009). The problems due to the research exemption are closely related to the problems of protection of cumulative innovations (Scotchmer, 1991).

Because of the farmers' exemption, seed varieties can be seen as durable goods. Conclusions similar to the Coase conjecture are reached by Perrin and Fulginiti (2008): the seed producer will exhaust his rent as prices decline over time. Due to the durable good nature of seeds, producers might prefer to introduce hybrid seed (similar to non-durable goods) even if it is less efficient (Ambec and al., 2008). To prevent farmers from saving seed, contracts such as Technology Use Agreements (TUAs) can also be used instead of "terminator" varieties (Yiannaka, 2014).

In these contributions, the innovation stage is not modeled. Galushko (2008) introduces it and finds that a patent system seems preferable to a PBR system except if the marginal cost of the seed producer exceeds the reproduction cost of farmers. Under this condition, it is more efficient to let farmers self-produce. Galushko (2008) does not take into account royalties on Farm-Saved Seeds (FSS). Our paper is a contribution to this latter stream of literature.

Our goal is to investigate the impact of the farmers' exemption on the equilibrium seed prices and the innovation decision in a monopoly setting. We consider a model in which farmers can either buy seeds or use their own saved seed (if allowed). A tax levied on self-producing farmers is partly paid to the seed producer.

The seed producer first decides to invest in a seed innovation. Once a (large or small) innovation has been discovered, he chooses to protect it with a PBR or a patent (if it is available) and determines seed prices for two periods. If protected by a costly patent, the seed innovation cannot be replanted by farmers as self-production is prohibited. This is the main difference between the two types of protection: a patent is costlier but it prevents self-production.

We find that in a PBR regime, depending on the tax level and the productivity of self-producing farmers, in equilibrium the producer adopts different pricing strategies (as in Ambec et al., 2008): either a 'durable good' strategy in which farmers self-produce in the second period or a 'non-durable good' strategy which makes self-producing not attractive to farmers. In the former case, the producer sets a high second-period price, such that farmers self-produce, and captures the farmers' surplus with an appropriate first-period price. In the latter case, he sets the second-period price such that farmers buy rather than self-produce in the second period.

If both PBR and patent regimes are available, in equilibrium, the seed producer will sometimes adopt a patenting strategy to prevent self-producing. However, because patenting is costly, he also adopts a durable good strategy with a PBR. Thus, allowing the seed producer to patent does not completely eliminate self-production.

Under a PBR regime, the research investment is a U-shape function of the tax. Initially, the producer reduces his investment as the tax increases. The rationale for this behavior is that as there are no gains from having a large innovation, he has no incentives to invest in it. Then, when his IPR decision changes for different innovation sizes, the investment is first independent of the tax, and it increases to reach a maximum for a high tax level. Compared to what would be socially optimal, the seed producer under or over invests for some values of the tax.

When both types of IPR are available, the seed producer's investment is a non-monotonic function of the tax, even though he intensifies his investment compared to the PBR regime. Our analysis shows that the total welfare is also a non-monotonic function of the tax. Patenting can enhance or reduce the total welfare compared to a situation where only PBRs are allowed.

Our findings suggest that, even though allowing seed producers to patent their seed innovations will boost innovation, its impact on the social welfare is ambiguous. An inappropriate level of tax might result in a decrease in welfare. Furthermore, each system of IPR seems to play a specific role: large innovations are more likely to be protected with a patent whereas small innovations will be protected with a PBR.

The paper is organized as follows. In Section 2, we present the model, the hypotheses and the timing of the game. Section 3 is devoted to the analysis of the price equilibria, and the decision of the seed producer to protect his innovation with a PBR or a patent. In Section 4, we analyze the research investment decisions depending on the innovation size and the IPR choice, and we compare them to the socially optimal investments. In Section 5, we analyze the incentives to innovate and the impact of the seed producer decisions on the total welfare. Section 6 concludes.

2 The model

We consider a three-period model ($t = 0, 1, 2$) with two types of agents: a seed producer and risk-neutral farmers. In period zero, the seed producer chooses a level of R&D investment I in order to discover a seed innovation that will increase the farmers' productivity. The innovation is either a large innovation $\overline{\theta}$ with probability $\mu(I)$ or a small innovation $\underline{\theta}$ with probability $(1 - \mu(I))$, where $\mu'(I) > 0$, $\mu''(I) < 0$ and $\mu(0) = 0$.

Once the innovation has been discovered, the seed producer decides whether to patent it or to protect it with a PBR, depending on which protection is available. In the presence of a patent, farmers are prohibited from self-producing whereas if the invention is protected with a PBR, farmers are allowed to re-use the seed as they see it fit. Thus, depending on the IPR method used by the seed producer, farmers can self-produce or not. Furthermore, patenting and PBR costs differ: the cost to patent is $c_P > 0$ whereas it is normalized to zero for the PBR.[13]

Once the seed producer introduces his protected innovation on the market, he produces it at marginal cost 0 and faces a continuum of farmers of mass 1. Each farmer buys zero or one units of seed during the first and second period. In the first period, each farmer chooses to buy either an old seed that generates a payoff π_0 or the new seed that generates a payoff $\theta\pi$, where $\theta \in \{\underline{\theta}, \overline{\theta}\}$ is the increase in productivity due to the investment I with $1 < \underline{\theta} < \overline{\theta}$ and $\pi > \pi_0$.

In the second period, each farmer chooses to buy either the old seed or the new one. If the new seed is protected with a PBR, each farmer has a third option: to self-produce by saving part of the first-period harvest and replanting it in the second period, which generates a payoff $\phi\theta\pi$ with $\phi < 1$. Self-producing farmers incurs a loss in productivity, which includes the cost of saving part of the harvest as well as the cost of the yield loss. To simplify, farmers are homogenous and ϕ represents the productivity of self-producing farmers with $\phi \in (0, 1)$.[14]

If a farmer decides to self-produce by saving part of his harvest and replanting it next year, he

[13] In 2004, Wright et al., (2007) estimated that patenting costs were around \$9400 whereas the estimated costs of PBR in Europe were about \$3600 per variety.

[14] The assumption of farmers homogeneity can be justified when farmers form a cooperative as it is the case in Canada, for instance.

has to pay a tax τ to the government. A fraction λ of the tax is paid back to the seed producer.[15] The remaining $(1-\lambda)\tau$ corresponds to the cost of collecting the tax by the government.

To simplify, we consider that the old seed variety has been on the market for some time, and is sold at a perfectly competitive price normalized to 0. Therefore, even in the absence of a tax, none of the farmers have an incentive to self-produce the old seed as $\pi_0 > \phi\pi_0$. Given the tax level and the investment decision, the seed producer chooses the new seed prices p_1 and p_2 for the two periods.[16] We normalize the discount factor to 1.

The timing of decisions is as follows. At period zero, the seed producer chooses his investment level I and the method of protection of his innovation (PBR or patent depending on which one is available) once he has discovered a seed innovation.

In the first period, he chooses seed prices for the first and second period, $\{p_1, p_2\}$. The farmers observe these prices. If the innovation is protected with a PBR, each farmer decides whether to buy the old seed at price 0 or the new seed at price p_1, and then decides whether to save some seed to self-produce during the next period.

In the second period, those who did not save part of their first-period harvest decide whether to buy the old or the new variety at price p_2 and those who self-produce pay the tax τ. If the innovation is patented, each farmer decides to buy the old seed or the new seed during the first and second periods.

3 Price Equilibrium, Plant Breeder Right and / or Patent

By using a backward induction argument, we first determine the equilibrium prices set by the seed producer. We then move to the IPR choice (PBR or patent) once the seed producer has discovered his innovation. Lastly, we analyze the optimal level of investment I.

In this section, we consider in turn the price equilibrium when the seed producer chooses a PBR and when he chooses a patent.

[15]In general, only 85% of the tax is transferred to the seed producer. See, for instance, `http://www.gnis.fr/index/action/page/id/106/search/CVO`, last accessed March 2014.

[16]We assume that the seed producer commits to these prices. In fact, if the time lapse between saving and planting is relatively short, it seems likely that the second-period price is determined before the replanting decision. However, if the period is rather long, it seems more realistic that the seed producer will not commit to a second-period price and will set its price in the second period. See Ambec *et al.* (2008) for a discussion of both commitment and non-commitment cases.

3.1 Plant Breeder Right Regime

If the seed innovation is protected with a PBR, the seed producer cannot prevent farmers from self-producing during the second period. However, he can adopt either a 'durable good' strategy in which he sells seeds only during the first period (and let farmers self-produce in the second period), or a 'non-durable' good strategy in which he sells seeds during the two periods.

We first analyze whether the 'durable good' strategy can be an equilibrium. At the beginning of the first period, the present value of the payoff of a farmer who decides to buy the seed in the first period at price p_1 and self-produce during the next period and pays the tax τ is

$$\theta\pi - p_1 + \phi\theta\pi - \tau.$$

This payoff must be compared with the payoffs that the farmer could obtain by choosing alternative buying strategies. He could decide to buy the old (respectively, new) seeds during both periods and would get $2\pi_0$ (respectively, $\theta\pi - p_1 + \theta\pi - p_2$); or to buy the old (respectively, new) seed during the first period and the new (resp., old) seed during the second period, and would obtain $\pi_0 + \theta\pi - p_2$ (resp., $\theta\pi - p_1 + \pi_0$).

The present value of the seed producer's payoff if he adopts this 'durable good' strategy is $p_1 + \lambda\tau$, as he sells the seed to all of the farmers in the first period and, then, gets a fraction λ of the tax paid by self-producing farmers in the second period. This 'durable good' strategy is an equilibrium in which the seed producer chooses the prices $\{p_1^D, p_2^D\}$ such that

$$\begin{aligned} p_1^D &= \theta\pi + \phi\theta\pi - \tau - 2\pi_0, \qquad (1) \\ p_2^D &> > \theta\pi - \pi_0, \end{aligned}$$

for $\phi \geq \phi_1$ with

$$\phi_1 \equiv \frac{\pi_0 + \tau}{\theta\pi}. \qquad (2)$$

This latter condition guarantees that replanting in the second period is more profitable than buying the old seed. It is satisfied for high values of ϕ, which means for a high self-producing productivity (or a low loss in productivity). For given π_0 and π, the cutoff value ϕ_1 is an increasing function of the tax τ, and a decreasing function of θ.

By choosing these prices, the seed producer insures that none of the farmers find it worthwhile to buy during the second period as p_2^D is too high. Thus, all of them self-produce and pay the tax τ during the second period, whereas they all buy the new seed during the first period.

The seed producer sells his new seed at price p_1^D to all of the farmers in the first period, and to none of them in the second period, but he still gets a fraction λ of the tax τ paid by the self-producing farmers, and thus, the present value of his payoff is

$$\Pi^D = \theta\pi(1+\phi) - 2\pi_0 - \tau(1-\lambda). \tag{3}$$

The farmers get

$$\theta\pi - p_1^D + \phi\theta\pi - \tau = 2\pi_0,$$

and the social welfare (which is the sum of the present value of both payoffs) is thus

$$W^D = \theta\pi(1+\phi) - \tau(1-\lambda). \tag{4}$$

The seed producer can however choose a 'non-durable good' strategy in which he sells during both periods and obtains the present value $p_1 + p_2$. This 'non-durable good' strategy can also be an equilibrium where he chooses the prices $\{p_1^{ND}, p_2^{ND_1}\}$ or $\{p_1^{ND}, p_2^{ND_2}\}$ such that

$$\begin{aligned} p_1^{ND} &= \theta\pi - \pi_0, \\ p_2^{ND_1} &= \theta\pi - \pi_0 \text{ for } \phi < \phi_1, \\ p_2^{ND_2} &= \theta\pi(1-\phi) + \tau \text{ for } \phi \geq \phi_1. \end{aligned} \tag{5}$$

The seed producer sets a second-period price such that all the farmers buy the new seed instead of self-producing. By setting both prices at $\theta\pi - \pi_0$ as it is the case for $\phi < \phi_1$, he guarantees that the farmers will not buy the old seed instead of the new one. At the same time, he must insure that farmers will not self-produce, which occurs only for $\phi < \phi_1$ if $p_2^{ND_1} = \theta\pi - \pi_0$. For higher values of ϕ ($\phi \geq \phi_1$), the latter price $p_2^{ND_1}$ will be too high and, thus, the seed producer must set a lower price equal to $p_2^{ND_2} = \theta\pi(1-\phi) + \tau$.

Therefore, for $\phi < \phi_1$, the seed producer adopts non-durable good strategy 1 with prices

$\{p_1^{ND}, p_2^{ND_1}\}$, and his equilibrium payoff is

$$\Pi^{ND_1} = 2(\theta\pi - \pi_0), \tag{6}$$

the farmers get $2\pi_0$, and the social welfare is

$$W^{ND_1} = 2\theta\pi.$$

For $\phi \geq \phi_1$, the seed producer adopts non-durable good strategy 2 with prices $\{p_1^{ND}, p_2^{ND_2}\}$, and his equilibrium payoff is

$$\Pi^{ND_2} = \theta\pi(2 - \phi) - \pi_0 + \tau, \tag{7}$$

the farmers get

$$\pi_0 + \phi\theta\pi - \tau,$$

and the social welfare is also

$$W^{ND_2} = 2\theta\pi = W^{ND_1} \equiv W^{ND}. \tag{8}$$

Given these equilibrium strategies, the seed producer chooses non-durable good strategy 1 with prices $\{p_1^{ND}, p_2^{ND_1}\}$ for $\phi < \phi_1$ (which is the only possible equilibrium), non-durable good strategy 2 with prices $\{p_1^{ND}, p_2^{ND_2}\}$ for $\phi_1 \leq \phi < \phi_2$, and the durable good strategy with prices $\{p_1^D, p_2^D\}$ for $\phi \geq \phi_2$ where

$$\phi_2 = \frac{\theta\pi + \pi_0 + \tau(2 - \lambda)}{2\theta\pi}. \tag{9}$$

When self-producing farmers have a high loss in productivity ($\phi < \phi_1$), the producer adopts a non-durable good strategy in which he sells the new seed at the same price during both periods, and all the farmers buy the new seed. As self-producing farmers become more productive ($\phi > \phi_1$), he reduces his second-period price in order to insure that farmers do not self-produce.

However, when self-producing farmers are very productive ($\phi > \phi_2$), the seed producer adopts a durable good strategy in which he does not have to insure that farmers do not self-produce anymore. In fact, he raises his second-period price to make sure that farmers will self-produce, and he also increases his first-period price in order to capture the entire farmers' surplus. We summarize these findings in the following Lemma.

Lemma 1 *Under a PBR regime, two different pricing strategies can be adopted in equilibrium by the seed producer:*

- *when $\phi \geq \phi_2$, a durable good strategy with prices $\{p_1^D, p_2^D\}$ as defined by (1);*
- *when $\phi < \phi_2$, a non-durable good strategy with prices $\{p_1^{ND}, p_2^{ND_2}\}$ for $\phi_1 \leq \phi < \phi_2$ and $\{p_1^{ND}, p_2^{ND_1}\}$ for $\phi < \phi_1$ as defined by (5).*

We represent these findings in Figure 1 where the axes are (τ, ϕ) for a given investment I.

Insert Figure 1

There are three different areas in Figure 1. In area (I), which corresponds to low values of the productivity of the self-producing farmers, the seed producer adopts non-durable good strategy 1 with prices $\{p_1^{ND}, p_2^{ND_1}\}$. In area (II), for higher values of the productivity ϕ and a level of the tax that is not too high, he adopts non-durable good strategy 2 with prices $\{p_1^{ND}, p_2^{ND_2}\}$, where $p_2^{ND_2} < p_2^{ND_1}$. In area (III), for high values of ϕ and relatively low tax levels, the seed producer adopts a durable good strategy $\{p_1^D, p_2^D\}$.

For a given level of self-producing farmer's productivity ϕ, we analyze the effect of a change in the tax level τ. For a relatively high level of ϕ, as the tax τ increases (from A to B in Figure 1), the welfare W^D as defined by (4) first decreases, and then jumps to W^{ND} as defined by (8) where it is constant. Initially, as a durable good strategy is adopted, the seed producer's benefit Π^D as defined by (3) decreases as τ increases, whereas the farmers' benefit, $2\pi_0$, is not affected. The total welfare is reduced due to the reduction in the seed producer's benefit.

At some point, the durable good strategy is no longer profitable and the seed producer switches to a non-durable good strategy in which both benefits are affected by an increase in τ (the farmers' benefit is reduced whereas the seed producer's benefit increases). Yet, these effects cancel out and the tax has no impact on the total welfare. Therefore as τ increases from small values, the welfare is not initially enhanced. As we change of regime, welfare increases.

Overall, the welfare is a non-monotonic function of the tax τ. If the tax is set at a relatively low level and the public authority is considering increasing it to benefit the seed producer, the effect might not be the one expected as the seed producer will initially be hurt by this increase.

3.2 Patent Regime

Under a patent regime, the durable good strategy is ruled out as farmers cannot self-produce in the second period. The available pricing strategy is thus a non-durable strategy $\{p_1^P, p_2^P\}$ in which the seed producer sets the prices such that

$$p_1^P = p_2^P = \theta\pi - \pi_0. \tag{10}$$

The seed producer's gross payoff is

$$\Pi_g^P = 2(\theta\pi - \pi_0),$$

the farmers get $2\pi_0$, and the gross social welfare is thus

$$W_g^P = 2\theta\pi.$$

The social welfare in case of patenting includes the patenting cost as well, such that the net social welfare is

$$W^P = 2\theta\pi - c_P. \tag{11}$$

This case is similar to the case of non-durable good strategy 1. We summarize the pricing strategy under a patent regime in the following Lemma.

Lemma 2 *Under a patent regime, an unique pricing strategy $\{p_1^P, p_2^P\}$ as defined by (10) is adopted in equilibrium by the seed producer.*

3.3 Choice between PBRs and Patents

If the two methods of protection are available, once the seed innovation has been discovered and the value θ has been realized (i.e., either a small innovation, $\underline{\theta}$, or a large one, $\overline{\theta}$), the seed producer must decide whether to patent it or to protect it with a PBR. In the former case, he must pay a patenting cost c_P, and thus, his patenting payoff is

$$\Pi^P = 2(\theta\pi - \pi_0) - c_P, \tag{12}$$

that must be compared with the payoff he would get from getting a PBR instead of a patent: Π^D as defined by (3) if a durable good strategy is adopted or Π^{ND_1} or Π^{ND_2} as defined by (6) and (7) if a non-durable good strategy is adopted.

Not surprisingly, our findings depend on the patenting cost. For a relatively high patenting cost, $c_P \geq (\theta\pi - \pi_0)/2$, the seed producer never patents as a patent is too costly. However, for lower values, $c_P < (\theta\pi - \pi_0)/2$, he will sometimes decide to patent. When self-producing farmers are not very productive, i.e., $\phi < \phi_1$ (area (I) in Figure 1), the seed producer will never patent as patenting and using a PBR generate the same gross payoff. Indeed, the seed producer sells his seed as a non-durable good even in the case of a PBR as farmers have a high loss in productivity if they self-produce.

When self-producing farmers are more productive, for $\phi_1 < \phi < \phi_2$ (area (II) in Figure 1), the seed producer prefers to patent if $\Pi^P > \Pi^{ND_2}$ or, equivalently, for $\phi > \phi_1^P$, where

$$\phi_1^P \equiv \frac{\pi_0 + c_P + \tau}{\theta\pi}. \tag{13}$$

In this case, the seed producer who adopts a non-durable good strategy with a PBR must reduce his second-period price to make sure farmers do not self-produce, which makes this strategy less attractive than patenting. However, because patenting is costly, there is an area in which the seed producer is better off by using a PBR, for $\phi_1 < \phi < \phi_1^P$.

Finally, turning to the last case, when self-producing farmers are very efficient, for $\phi_2 < \phi < 1$, (area (III) in Figure 1), the seed producer prefers to patent if $\Pi^P > \Pi^D$ or, equivalently, for $\phi < \phi_2^P$, where

$$\phi_2^P \equiv \frac{\theta\pi - c_P + \tau(1-\lambda)}{\theta\pi}. \tag{14}$$

In this case, the durable good strategy adopted by the seed producer when he chooses a PBR is more profitable than patenting if self-producing farmers have a high productivity. This allows the seed producer to increase his first-period price.

Figures 2.*a*. and 2.*b*. illustrate these findings for different values of c_P. Figure 2.a. represents the case where the patenting cost is not too high, i.e., $c_P < (1-\lambda)(\theta\pi - \pi_0)/(2-\lambda)$, whereas Figure 2.b. represents the case where $(1-\lambda)(\theta\pi - \pi_0)/(2-\lambda) < c_P < (\theta\pi - \pi_0)/2$. If patenting is too costly, the area where the seed producer patents will shrink, as patenting is less attractive.

Insert Figures 2.a. and 2.b.

In what follows we assume that, for any level of θ, the patenting cost is such that

$$0 < c_P < \frac{1-\lambda}{2-\lambda}(\theta\pi - \pi_0), \tag{15}$$

and, therefore, we only consider the situation represented by Figure 2.a.[17]

We summarize these findings in the following Proposition.

Proposition 1 *When both patent and PBR regimes are available, and if the patenting cost satisfies (15), the seed producer prefers a patent over a PBR*

- *when $\phi > \phi_1^P$ if a non-durable good strategy is adopted under the PBR regime,*
- *when $\phi < \phi_2^P$ if a durable good strategy is adopted under the PBR regime.*

Even for a relatively low patenting cost, the seed producer might prefer to let farmers self-produce. From these findings we directly derive the following Corollary.

Corollary 1 *When both patent and PBR regimes are available, self-production cannot be completely eliminated.*

Starting from a PBR regime as it is the case in Europe, the introduction of a patent regime will not completely eliminate self-production; for some parameter values, the seed producer still prefers to protect his invention with a PBR rather than with a more expensive patent. In our model, the patenting option reduces the likelihood of adopting a durable good strategy even if the patent system does not fully prevent self-production by farmers.

Furthermore, for a relatively high level of ϕ (relatively low loss in productivity from self-producing), as τ increases, the welfare W^D as defined by (4) first decreases, then it is constant at W^P as defined by (11) before jumping to W^{ND} as defined by (8) when finally a non-durable good strategy is adopted.

If the public authority sets initially a too low level of τ, the welfare will not be maximized. Then, by increasing the tax, the welfare will first decrease before getting to its maximum level.

[17] The findings in the case of Figure 2.b. are qualitatively similar to those of Figure 2.a.

4 Research Investment Decision

At the outset of the game, the seed producer makes an investment decision that occurs before the realization of the increase in productivity is known. Therefore, based on the findings of the previous section, for each potential increase in productivity $\underline{\theta}$ and $\overline{\theta}$ we define the equilibrium payoffs. We first consider the case where only PBRs are allowed, and then the case where both patent and PBR regimes are available.

4.1 Plant Breeder Right Regime

For a given size of the seed innovation $\theta \in \{\underline{\theta}, \overline{\theta}\}$ we have determined the pricing strategies of the producer when he protects his innovation with a PBR in the previous section. To calculate his optimal investment, we identify his pricing strategies for $\underline{\theta}$ and $\overline{\theta}$ and the corresponding payoffs for any possible ϕ and τ. It also implies that the cut-off values ϕ_1 and ϕ_2 as defined by (2) and (9) depend also on $\underline{\theta}$ and $\overline{\theta}$ such that there are now four cut-off values, $\overline{\phi}_1$, $\overline{\phi}_2$, $\underline{\phi}_1$ and $\underline{\phi}_2$.

The findings in the case of a PBR regime are illustrated in Figure 3.1.

Insert Figure 3.1

Figure 3.1. is similar to Figure 1, except that there are now four cut-off values $\overline{\phi}_1$, $\overline{\phi}_2$, $\underline{\phi}_1$ and $\underline{\phi}_2$. As $\underline{\theta} < \overline{\theta}$, $\underline{\phi}_1 > \overline{\phi}_1$ and $\underline{\phi}_2 > \overline{\phi}_2$. We assume that $\overline{\phi}_2 > \underline{\phi}_1$ which is equivalent to

$$\overline{\theta} < (2 - \lambda)\underline{\theta} - (1 - \lambda)\frac{\pi_0}{\pi}. \tag{16}$$

Condition (16) is obtained by insuring that the value of τ such that $\overline{\phi}_2 = 1$ is smaller than the value of τ such that $\underline{\phi}_1 = 1$. If this condition is satisfied, then for any value of $\phi < 1$, $\overline{\phi}_2 > \underline{\phi}_1$. This assumption states that the large innovation is not too large compared to the small one. Relaxing this assumption does not change qualitatively our findings, while it does add many cases to analyze.

We now determine the benefit functions for the five different areas defined in Figure 3.1.

In area (1), for each value of θ, the seed producer will adopt the same non-durable good strategy 1 with prices $\{\overline{p}_1^{ND}, \overline{p}_2^{ND_1}\}$ and $\{\underline{p}_1^{ND}, \underline{p}_2^{ND_1}\}$. If a small innovation $\underline{\theta}$ has been discovered, the seed producer obtains a benefit

$$\underline{\Pi}^{ND_1} = 2(\underline{\theta}\pi - \pi_0),$$

whereas he gets

$$\overline{\Pi}^{ND_1} = 2(\overline{\theta}\pi - \pi_0)$$

if a large innovation $\overline{\theta}$ has been discovered.

In area (2), the seed producer who has discovered a small innovation adopts the same non-durable good strategy 1 as before with associated prices $\{\underline{p}_1^{ND}, \underline{p}_2^{ND_1}\}$ that generates a payoff $\underline{\Pi}^{ND_1}$, while if he has discovered a large innovation he adopts the other non-durable good strategy 2 with prices $\{\overline{p}_1^{ND}, \overline{p}_2^{ND_2}\}$ and obtains

$$\overline{\Pi}^{ND_2} = \overline{\theta}\pi(2 - \phi) - \pi_0 + \tau.$$

In area (3), the strategy adopted by the seed producer is the same: non-durable good strategy 2 with prices $\{\overline{p}_1^{ND}, \overline{p}_2^{ND_2}\}$ and $\{\underline{p}_1^{ND}, \underline{p}_2^{ND_2}\}$ and the benefits are $\overline{\Pi}^{ND_2}$ and

$$\underline{\Pi}^{ND_2} = \underline{\theta}\pi(2 - \phi) - \pi_0 + \tau.$$

In area (4), a seed producer who has discovered a large innovation adopts a durable good strategy with prices $\{\overline{p}_1^{D}, \overline{p}_2^{D}\}$ and obtains

$$\overline{\Pi}^{D} = \overline{\theta}\pi(1 + \phi) - \tau(1 - \lambda) - 2\pi_0.$$

In the case of a small innovation, the seed producer adopts the previous non-durable good strategy with prices $\{\underline{p}_1^{ND}, \underline{p}_2^{ND_2}\}$ and gets $\underline{\Pi}^{ND_2}$.

Finally, in area (5), the seed producer adopts a durable good strategy for any size of the innovation and, thus, the benefits are $\overline{\Pi}^{D}$ for a large innovation and

$$\underline{\Pi}^{D} = \underline{\theta}\pi(1 + \phi) - \tau(1 - \lambda) - 2\pi_0$$

for a small innovation.

Starting from a small value of τ, for low values of the farmers' self-productivity parameter, both small and large innovations generate the same non-durable good strategy 1. As ϕ increases, both types of innovator still adopt a non-durable good strategy, except that now the seed producer who has discovered a large innovation must reduce his second-period price in order to prevent self-production. Indeed, a large innovation generates a higher benefit to farmers who have more incentives to self-produce.

As some point, as ϕ keeps increasing, the seed producer with the large innovation switches to a durable good strategy as it is not worth trying to prevent self-production, while a small innovation still generates a non-durable good strategy. Eventually, when ϕ is very high, only a durable good strategy is adopted.

As different strategies are adopted depending on the size of the innovation, investment decisions will be different in each of the areas defined in Figure 3.1. For instance, in area (1), the seed producer chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^{ND_1} + (1 - \mu(I))\underline{\Pi}^{ND_1} - I\},$$

which gives the following first order condition

$$\mu'(I)2(\overline{\theta} - \underline{\theta})\pi - 1 = 0.$$

We denote $I^{\overline{ND}_1,\underline{ND}_1}$ the optimal level of investment when non-durable strategy 1 adopted.

In area (2), the seed producer still adopts non-durable good strategy 1 when he has discovered a small innovation, but he now adopts non-durable good strategy 2 when he has discovered a large innovation. Therefore, *ex ante*, he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^{ND_2} + (1 - \mu(I))\underline{\Pi}^{ND_1} - I\},$$

which gives the first order condition

$$\mu'(I)[2(\overline{\theta} - \underline{\theta})\pi + \pi_0 + \tau - \overline{\theta}\phi\pi] - 1 = 0.$$

We denote $I^{\overline{ND}_2,\underline{ND}_1}$ the optimal level of investment solution of this program.

For each of the five areas defined in Figure 3.1. we determine the optimal level of investment I (see appendix for calculations). Even without further specification on the function $\mu(I)$, we can analyze and compare the five equilibrium investments. We represent these investments as a function of τ in Figure 4.1. for $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$.

Insert Figure 4.1

The optimal investment function has some kind of U-shape. For low values of τ, as the durable good strategy is adopted no matter what the innovation size is, there is no extra gain in having a large innovation as $d(\overline{\Pi}^D - \underline{\Pi}^D)/d\tau = 0$. The optimal investment is independent of τ as there is no extra benefit from having a large innovation, so the seed producer does not have to intensify or reduce his investment as τ increases.

As τ increases, non-durable good strategy 2 becomes more attractive to the seed producer who has discovered a small innovation, while the durable good strategy is still adopted by a seed producer who has discovered a large innovation. In this area, the extra gain from having a large innovation decreases with τ as $d(\overline{\Pi}^D - \underline{\Pi}^{ND_2})/d\tau < 0$ and, therefore, the seed producer reduces his R&D investment.

Then, we reach an area where the seed producer who has discovered either a large or a small innovation decides to adopt non-durable good strategy 2 and, in this case, there is no gain from having a large innovation. The optimal investment becomes again independent of τ.

As non-durable good strategy 1 becomes more attractive to the seed producer with a small innovation, the extra gain from having a large innovation increases with τ as $d(\overline{\Pi}^{ND_2} - \underline{\Pi}^{ND_1})/d\tau > 0$. Then, for relatively large values of τ, non-durable good strategy 1 is adopted for large and small innovations and the investment is constant at its maximum level.

We summarize these findings in the following Lemma.

Lemma 3 *If $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$, under a PBR regime, the optimal research investment level is first constant, then decreases, increases and reaches its maximum level as τ increases.*

These optimal levels of research investment can be compared to the socially optimal levels of investment that maximize the total welfare. For each area of Figure 3.1. we determine the total welfare depending on the size of the innovation and then we calculate the socially optimal investments (see appendix for the calculations). The findings are reported in Figure 4.1.1.

Insert Figure 4.1.1

When τ is small (which corresponds to area (5) in Figure 3.1.) or very big (area (1) in Figure 3.1.), both levels of privately and socially optimal investment coincide. The maximum level of investment is reached for high values of τ.

For intermediate values of τ (areas (2) and (3) in Figure 3.1.), the seed producer underinvests in research. In fact, when he adopts non-durable good strategy 2 for any innovation size, farmers benefits from a large innovation. So, from a social viewpoint, it is optimal to discover a large innovation. Formally, for values of $\tau \in [\tau_1, \tau_4]$ the seed producer underinvests where τ_1 if the value of τ for which $\overline{\phi}_2(\tau) = \phi$, and τ_4 is the value of τ for which $\overline{\phi}_1(\tau) = \phi$.

In area (4) (in Figure 3.1.) the seed producer overinvests compared to what is socially optimal. He uses a durable good strategy when he discovers a large innovation and non-durable good strategy 2 when he discovers a small innovation. The benefit of the farmers is lower under the durable good strategy than the non-durable good strategy as $2\pi_0 < \pi_0 + \phi\underline{\theta}\pi - \tau$ is always satisfied. Formally, the seed producer overinvests for $\tau \in [\tau_0, \tau_1]$, where τ_0 is the value of τ for which $\underline{\phi}_2(\tau) = \phi$.

Thus, the welfare gain from having a large innovation is smaller than the gain of the seed producer. In other words, there are less incentives from a social viewpoint in trying to obtain a large innovation than from the private viewpoint. Therefore, the seed producer overinvests.

We summarize our findings in the following Proposition.

Proposition 2 *If $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$, under a PBR regime, the seed producer can underinvest or overinvest in research compared to what is socially optimal depending on the value of τ.*

To summarize, when farmers benefit from a large innovation, the seed producer underinvests, whereas when they do not benefit from having a large innovation, he overinvests.

4.2 Patent and Plant Breeder Right Regimes

If both patent and PBR systems are available, the seed producer might decide to patent his innovation instead of protecting it with a PBR. If he has discovered a small innovation, his payoff from patenting is

$$\underline{\Pi}^P = 2(\underline{\theta}\pi - \pi_0) - c_P,$$

whereas it is

$$\overline{\Pi}^P = 2(\overline{\theta}\pi - \pi_0) - c_P,$$

if he has discovered a large innovation.

In each of the five areas defined in Figure 3.1., we compare the benefit of the seed producer if he protects his innovation with a patent or a PBR. In area (1), where non-durable good strategy 1 is always adopted under a PBR regime whatever the size of the innovation, the patenting strategy is never preferred to a PBR as, for any θ, the inequality $2(\theta\pi - \pi_0) - c_P > 2(\theta\pi - \pi_0)$ is always satisfied for $c_P > 0$. In other words, patenting or choosing a PBR lead to identical gross payoffs but patenting is costlier.

In area (2), when the innovation is small, a PBR is always preferred to a patent whereas a patent is preferred to a PBR when the innovation is large for $\phi > \phi_1^P(\overline{\theta})$. In area (3), patenting a large innovation can make the seed producer better off if $\phi > \phi_1^P(\overline{\theta})$, but also patenting a small innovation can be chosen for $\phi > \phi_1^P(\underline{\theta})$.

In area (4), the seed producer will patent his large innovation if $\phi < \phi_2^P(\overline{\theta})$, and his small innovation if $\phi > \phi_1^P(\underline{\theta})$. In area (5), patenting will occur if $\phi < \phi_2^P(\theta)$. We assume further that

$$(\overline{\theta} - \underline{\theta})\pi < c_P < \frac{1-\lambda}{2-\lambda}(\underline{\theta}\pi - \pi_0) - \frac{(\overline{\theta} - \underline{\theta})}{2-\lambda}\pi. \quad (17)$$

We represent these different areas in Figure 3.2.

Insert Figure 3.2

There are now seven different areas as, depending on the size of the innovation, the seed producer might choose different property rights. Indeed, in areas (4) and (6), a large innovation will be protected with a patent whereas a small one will be protected with a PBR. The size of the innovation will impact the patenting decision. We summarize this finding in the following Proposition.

Proposition 3 *The seed producer has a tendency to patent large innovations and to use a PBR* *for small innovations.*

For each area in Figure 3.2., we determine the investment decision of the seed producer (see appendix for all of the investment levels). For instance, in area (4), he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^P + (1-\mu(I))\underline{\Pi}^{ND_2} - I\}.$$

We denote $I^{\overline{P},\underline{ND}_2}$ the optimal level of investment solution of this program.

To clarify the impact of the tax, we choose a high level of ϕ for which all seven cases displayed in Figure 3.2. can be obtained. We represent the evolution of the optimal investment as a function of τ in Figure 4.2. (similar to Figure 4.1).

Insert Figure 4.2

When the seed producer can choose between a patent and a PBR, the optimal investment is higher than under a strict PBR regime. When the seed producer finds it worthwhile to patent a large innovation but still to use a durable good strategy with a PBR for a small innovation, the investment is increasing with τ. When the seed producer patents both small and large innovations, the investment is at its highest level, the same as under a PBR regime with non-durable good strategy 1. However, when the seed producer patents his large innovation and uses a non-durable good strategy for his small innovation, his investment decision is decreasing with τ. We summarize these findings in the following Lemma.

Lemma 4 *If $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$, when both patent and PBR regimes are available, the optimal research investment is a non-monotonic function of τ. Overall, the investment level is higher than under a PBR regime alone.*

If the PBR regime is the only regime that is available (as it is the case in Europe), the optimal investment levels are lower than if both patent and PBR regimes are available. Thus, combining PBR and patent regimes allows to intensify the research investment.

We now compare the optimal private investment levels with the socially optimal levels of investment. We find that the seed producer can over or under invest (see appendix for the calculations and comparisons) as illustrated in Figure 4.2.1.

Insert Figure 4.2.1

We summarize these findings in the following Proposition.

Proposition 4 *If $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$, under both PBR and patent regimes, the seed producer can overinvest or underinvest in research compared to what is socially optimal depending on the value of τ.*

For low and high values of τ, the private and socially optimal levels of investment coincide.

For intermediate values of τ, the seed producer will overinvest or underinvest. In area (4) in Figure 3.2., the seed producer protects his innovation with a patent when he has discovered a large innovation and uses non-durable good strategy 2 if it is a small innovation. From a society viewpoint, the seed producer should not invest too much. This is due to the fact that when he finds a small innovation, the seed producer reduces his second-period price to prevent farmers from self-producing, which makes them better off. Thus, farmers gain less from a patented large innovation than a small innovation with non-durable good strategy 2. Overall, society does not benefit from a large innovation. On the other hand, from the viewpoint of the seed producer, even though his investment is decreasing with τ, he still invests more than what would be socially optimal. Formally, for values of $\tau \in [\tau_3, \tau_4]$ the seed producer underinvests where τ_3 is the value of τ for which $\overline{\phi}_1^P(\tau) = \phi$.

In areas (2) and (3) in Figure 3.2., the seed producer uses non-durable good strategies and will underinvest. In area (3), the seed producer has less to gain from a large innovation than does society. Farmers benefit from non-durable good strategy 2 more than the seed producer. In area (2), even though the seed producer uses non-durable good strategy 1 with a small innovation, society still gains more from a large innovation than does the seed producer. Formally, for values of $\tau \in [\tau_2, \tau_3]$ the seed producer overinvests where τ_2 is the value of τ for which $\underline{\phi}_1^P(\tau) = \phi$.

Under both PBR and patent regimes, the seed producer will less likely underinvest compared to the case with only a PBR regime. We summarize this finding in the following Corollary.

Corollary 2 *If $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$, the seed producer underinvests for*

- $\tau \in [\tau_1, \tau_4]$ *under a PBR regime,*

- $\tau \in [\tau_3, \tau_4]$ *under both PBR and patent regimes where* $\tau_3 > \tau_1$.

In terms of investment, patenting boosts the investment compared to the case with only a PBR regime. The investment as a function of ϕ has also a U-shape form with only a PBR regime, and it is a non-monotonic function when both patent and PBR regimes coexist (see Figure 4.3. and the appendix).

Insert Figure 4.3

The rationale for analyzing investment decisions as a function of τ is to consider systems where a tax is paid by self-producing farmers to the seed producer. However, countries such as Canada and the U.S. do not have a royalty or a tax system yet. Furthermore, in the U.S. both patent and PBR regimes coexist and, in practice, they are both used by seed companies.

To understand why a seed company will use both IPRs systems, we assume that $\tau = 0$, and, in a graph (c_P, ϕ) we analyze the patenting and PBR decisions with associated pricing decisions that we represent in Figure 3.3.

Insert Figure 3.3

For a given patenting cost c_P that satisfies (15) with $\tau = 0$, the seed producer prefers a patent over a PBR for intermediate values of ϕ. When self-producing farmers are very productive (high ϕ), he adopts a durable strategy with a PBR for any size of his innovation. For very unproductive self-producing farmers (low ϕ), he always adopts non-durable good strategy 1.

For intermediate values of ϕ, he patents his large innovation, whereas he uses either a non-durable good strategy or a durable good strategy for his small innovation, depending on the value of ϕ.In fact, the patenting cost c_P could be could be used as a policy tool by the government.

5 Incentives to Innovate and Welfare

In this section, we first characterize the incentive to innovate of the seed producer and, then, we analyze the impact of the optimal private investment on social welfare. In order to calculate both profit and welfare functions evaluated at each of the optimal levels of investment, we consider the following functional form[18]

$$\mu(I) = 1 - exp^{-I}, \tag{18}$$

which satisfies the conditions $\mu'(I) > 0$, $\mu''(I) < 0$ and $\mu(0) = 0$.

5.1 Incentives to Innovate

We use the traditional definition of "pure" incentive to innovate (Arrow, 1962), which corresponds to the difference in profits that the seed producer can earn if he invests in R&D compared to what he would earn if he did not invest. In our setting, not investing in R&D is equivalent to selling the old seed in a perfectly competitive market and obtaining a null payoff. Therefore, incentives to innovate are represented by the *ex ante* expected profit of the seed producer

$$\mu(I)\overline{\Pi} + (1 - \mu(I))\underline{\Pi} - I,$$

evaluated at each optimal level of investment and corresponding profit $\overline{\Pi}$ and $\underline{\Pi}$.

Under a PBR regime, in area (1) in Figure 3.1., the *ex ante* expected profit of the seed producer is

$$\begin{aligned} \Pi^{\overline{ND}_1,\underline{ND}_1} &= \mu(I^{\overline{ND}_1,\underline{ND}_1})\overline{\Pi}^{ND_1} + (1 - \mu(I^{\overline{ND}_1,\underline{ND}_1}))\underline{\Pi}^{ND_1} - I^{\overline{ND}_1,\underline{ND}_1} \\ &= \mu(I^{\overline{ND}_1,\underline{ND}_1})2(\overline{\theta} - \underline{\theta})\pi + 2(\underline{\theta}\pi - \pi_0) - I^{\overline{ND}_1,\underline{ND}_1}, \end{aligned}$$

which is independent of τ, since $I^{\overline{ND}_1,\underline{ND}_1}$ is independent of τ. For each of the five different areas in Figure 3.1. we compute the different levels of *ex ante* expected profit that we represent in a graph (τ, Π) in Figure 5.1. We also assume that $\phi > (\underline{\theta}\pi + \pi_0)/2\underline{\theta}\pi$.

Insert Figure 5.1

Under a PBR regime, as τ increases, the incentive to innovate first decreases, reaches a minimum level before it increases. The strongest incentives to innovate are reached when the seed producer uses non-durable good strategy 1 for both innovation sizes.

Initially, as τ increases the *ex ante* expected benefit of the seed producer decreases through

[18] As a robustness check, we consider another function in the extension of the model (see appendix).

the profits for small and large innovations. As more taxes are collected from farmers, the price charged by the seed producer, p_1^D, decreases and so does his payoff. This is due to the fact that only a fraction λ of the tax collected is paid back to the seed producer.

As τ increases further, the seed producer uses non-durable good strategy 2 for his small innovation but still adopts a durable good strategy for his large innovation. As the tax increases, the profit from a large innovation is reduced through a reduction of $\underline{p}_1^D$, but the profit from a small innovation increases. However, overall, the negative impact on the large innovation outweighs the positive impact on the small one. In other words, the loss associated with the large innovation is larger than the gain associated with a small innovation.

As τ increases further, the seed producer uses non-durable good strategy 2 for both types of innovation. As the tax increases, both profit levels increase. An increase in the *ex ante* expected profit is due to an increase in the small innovation profit.

When it becomes more interesting to use non-durable good strategy 1 for a small innovation, the incentive to innovate still increases but at a smaller rate as only the profit from a large innovation increases with τ.

For larger values of τ, the seed producer always uses non-durable good strategy 1 for both types of innovation and, thus, his *ex ante* expected profit is no longer affected by a change in τ.

Due to the different pricing strategies adopted by the seed producer depending on the tax value, the incentive to innovate is U-shaped. Thus, a PBR regime does not necessarily boost research incentives. In fact with an inappropriate tax level, incentives can be reduced.

Under both regimes, we calculate the *ex ante* expected profit for each of the seven areas in Figure 3.2. We graphically illustrate these incentives to innovate in Figure 5.2.

Insert Figure 5.2

Under both PBR and patent regimes, the incentive to innovate has also a U-shape, but it is higher than in the case of a unique PBR regime. Compared to the previous case where only PBRs are offered, there are three areas for which the incentives differ. In the first one, the seed producer uses a durable good strategy with a PBR for his small innovation while he prefers to patent his large innovation. This results in a decrease of the incentive but at a lower rate. In fact, the tax increase has only an impact on the small innovation profit, whereas in the case with only PBRs it would affect the profits for both types of innovation.

Then, in the second area where incentives diverge, the seed producer always patents both types of innovation, which makes the expected profit independent of the tax τ. However, because of the patenting cost, this is not the highest incentive level.

In the third area with different incentives, the seed producer uses non-durable good 2 with a small innovation, which increases his incentive to innovate as τ increases. This increase is entirely due to the small innovation profit. However, this increase is smaller than when the seed producer uses non-durable good strategy 2 for both types of innovations.

Allowing the seed producer to choose between a patent and a PBR to protect his innovation boosts the incentive to innovate compared to the case where he can only use a PBR. Thus, the patent regime restores some of the lack of incentive to innovate. We summarize these results in the following Proposition.

Proposition 5 *The incentive to innovate is initially decreasing with the tax τ, and then it increases. The highest incentive to innovate is reached for high levels of the tax. When both PBR and patent regimes are available, the incentive to innovation is higher than when only a PBR regime is offered.*

An inappropriate level of tax τ will likely have to opposite effect of what it was initially levied for: reduce the incentive to innovate instead of boosting innovation. When setting up a tax level, the public authority should account for the impact of the tax on the seed producer's pricing strategies and protection strategies.

5.2 Welfare Analysis

In this section, we calculate the social welfare function evaluated at the privately optimal levels of investment. Based on the specific functional form (18), and by using the findings of the previous section regarding the optimal values of the investment, we plot the welfare function in Figure 6.1. in the case of the PBR regime.

Insert Figure 6.1

The durable good strategy adopted by the seed producer always reduces the welfare as τ

increases. Then, as the seed producer decides to use a non-durable good strategy for a small innovation, the welfare increases in a non-monotonic way until it reaches its maximum when the seed producer uses the same non-durable good 1 for both large and small innovations. Under a PBR regime the welfare reaches a maximum when the seed producer does not allow self-producing, for large values of τ.

When both regimes are available, we represent the welfare function in Figure 6.2.

Insert Figure 6.2

Allowing the seed producer to choose between the two types of IPR does not always enhance welfare. As long as the patenting strategy prevents self-production by farmers (this replaces a durable good strategy), the welfare is enhanced. Farmers obtain the same surplus ($2\pi_0$) whereas the seed producer gains from patenting. Moreover, when the patenting strategy replaces non-durable good strategy 2, farmers are worse off and, overall, the welfare is reduced. This happens when the seed producer decides to patent a large innovation and uses a PBR with non-durable good strategy 2 for a small innovation. In this case, a rise of τ implies a decrease in both investment and welfare as the probability to obtain a small innovation increases.

Thus, the maximum investment is obtained for two strategies, patent or PBR when the tax prevents seed saving, whereas the maximum welfare is only reached for a PBR strategy when the fee prevents seed saving. We summarize these findings in the following Proposition.

Proposition 6 *The welfare is a non-monotonic function of the tax τ, and is not always enhanced when both PBR and patent regimes are offered.*

An efficient combination of PBRs and tax should be such that the tax is high enough so that farmers do not self-produce, and the seed producer does not use a durable good strategy. In fact, choosing non-durable good strategy 1 with a PBR is equivalent to a patenting strategy, but it is less costly for the seed producer.

6 Conclusion

The aim of this paper is to highlight the problem of incentives to innovate due to seed saving that decreases the seed producer's profit. Private firms innovate only if their payoffs exceed their costs, especially R&D. Therefore, the loss incurred due to seed saving may decrease private investment. In many countries, to correct the incentive problem, self-producing farmers must pay a tax to seed companies. We thus construct a theoretical model to analyze the consequences of the introduction of this tax on the seed producer's behavior.

We first analyze the equilibrium strategies of a seed producer depending on the seed saving productivity and the tax level of chosen by public authorities. For a high (respectively, low) productivity and a low (respectively, high) tax level, the seed producer chooses a durable good strategy (respectively, non-durable good strategy). Moreover, we find that the introduction of the patent system does not necessarily prevent self-production by farmers.

We then consider an endogenous innovation process where the seed producer discovers either a small or a large invention, depending on the intensity of his investment. When self-producing farmers are very productive, the seed producer prefers to protect his innovation with a PBR. The introduction of a tax can reduce the incentive to innovate and the welfare. However, the private optimal investment is equal to the social optimal investment.

For intermediate values of the productivity of self-producing farmers, the tax has an ambiguous effect on the optimal investment, the incentive to innovate and the welfare. The introduction of the patent system increases the incentive to innovate but has an ambiguous effect on the welfare due to higher patenting cost.

When self-producing farmers are not very efficient, even if a patent is allowed, the seed producer protects his innovation with a PBR. The introduction of a tax can increase the optimal investment, the incentive to innovate and the welfare.

Very productive self-producing farmers can be found in the wheat market. In fact, less private investments and less patenting are observed in the wheat market compared to other seed markets in the U.S. One explanation is the lack of incentive to innovate due to self-production. Our model provides another explanation: it might be optimal for the seed producer to let farmers self-produce if they have a very high productivity. As a consequence, seed producers prefer to protect their innovations with a PBR.

On the other extreme, maize varieties are mainly hybrid which makes self-production not attractive for farmers. Our model shows that seed producers prefer to use a PBR because it is less costly than a patent. However, there are many patents on maize in the U.S. In fact, our analysis does not take into account the intense competition in maize varieties. Due to higher competition, seed producers might prefer to patent their innovation.

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Figure 1: Seed producer strategies under a PBR regime

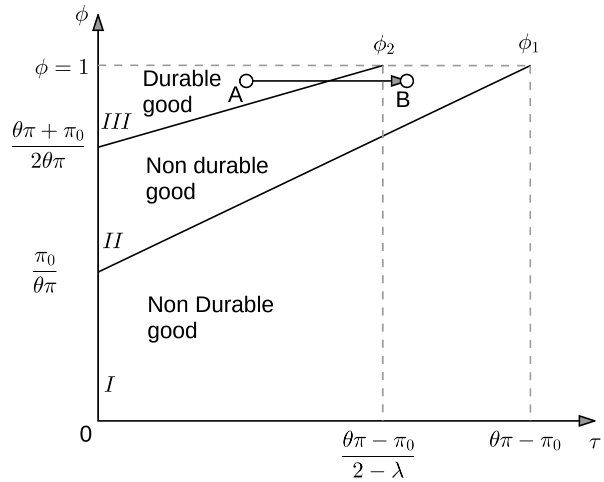
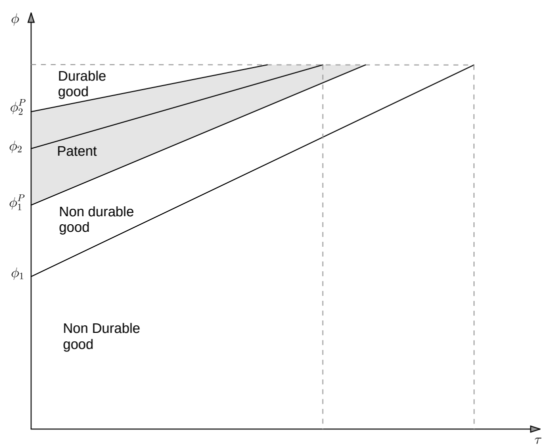
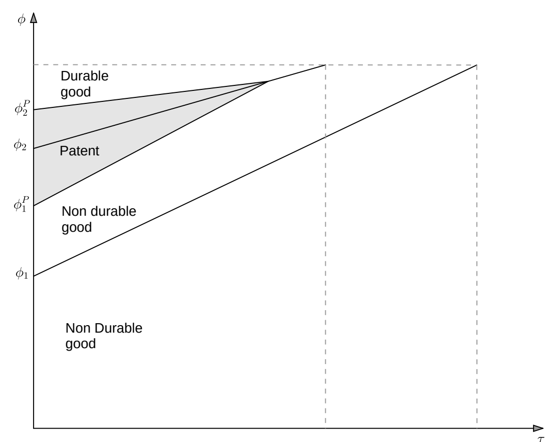


Figure 2: Seed producer strategies under both PBR and patent regimes



(a) For $0 < c_P < \frac{1-\lambda}{2-\lambda}(\theta\pi - \pi_0)$



(b) For $\frac{1-\lambda}{2-\lambda}(\theta\pi - \pi_0) < c_P < \frac{1}{2}(\theta\pi - \pi_0)$

Figure 3.1: Seed producer strategies under a PBR regime with $\theta \in \{\underline{\theta}, \overline{\theta}\}$

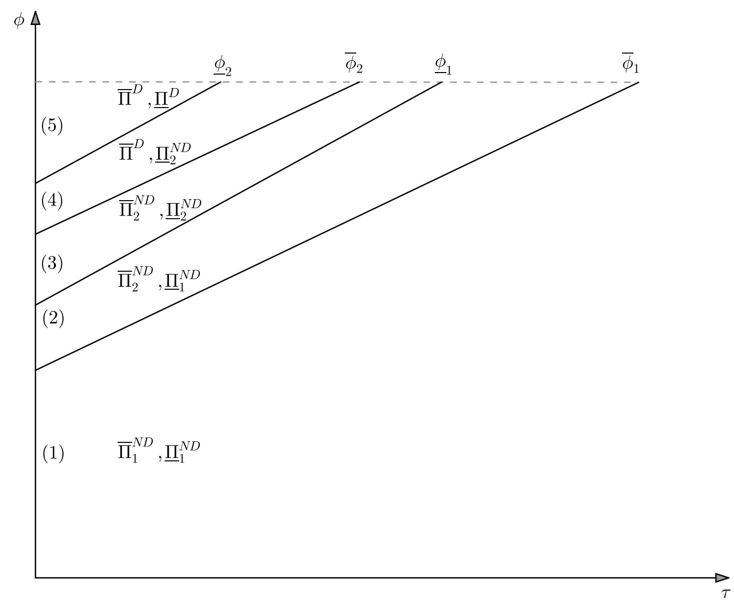


Figure 4.1: Optimal investment under a PBR regime

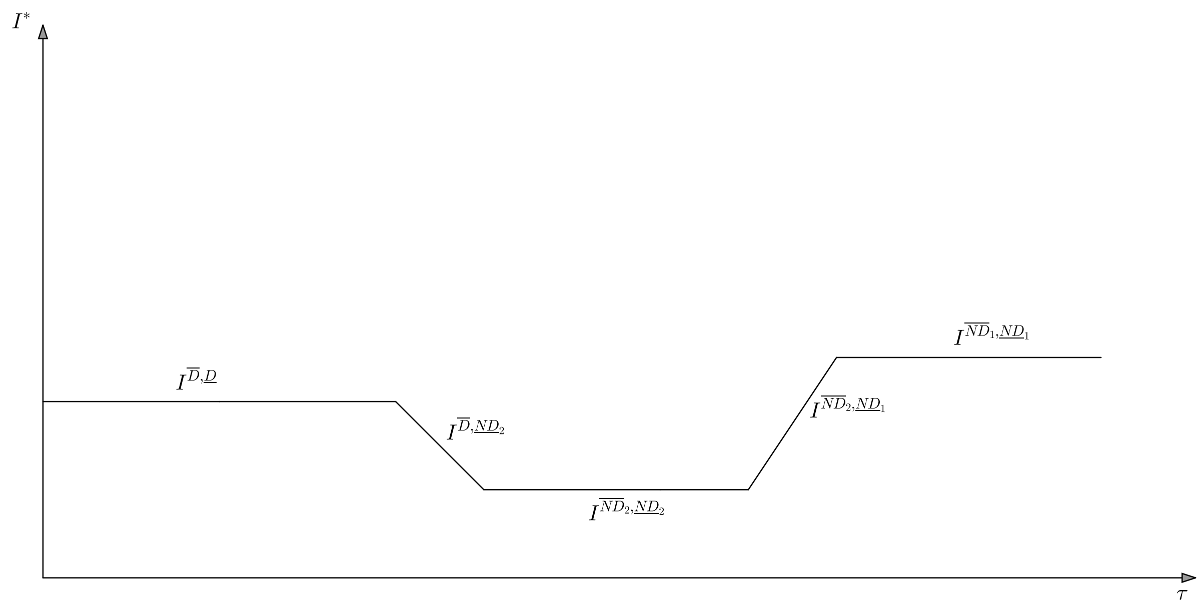


Figure 4.1.1: Private and social optimal investments under a PBR regime

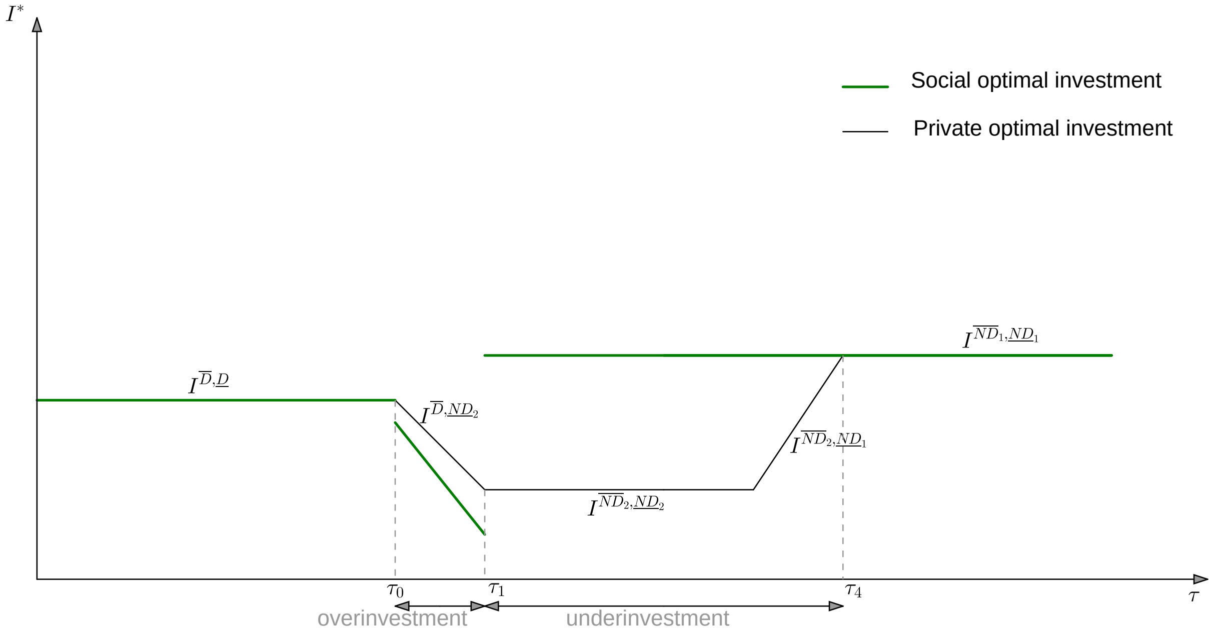


Figure 3.2: Seed producer strategies under both PBR and patent regimes with $\theta \in \{\underline{\theta}, \overline{\theta}\}$

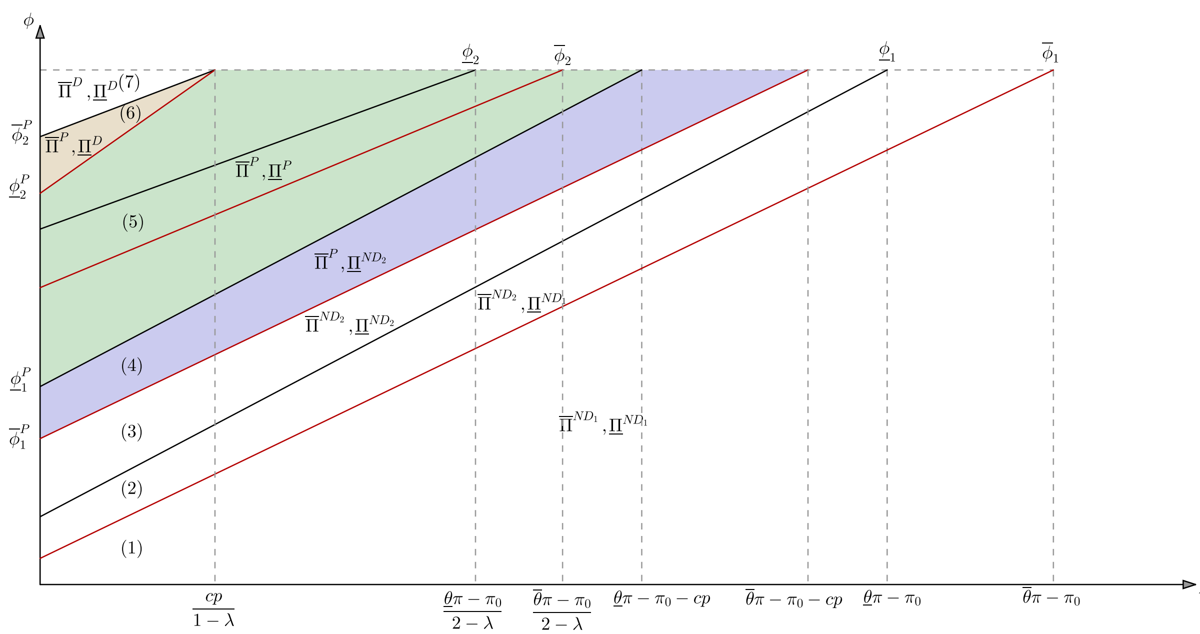


Figure 4.2: Optimal investment under both PBR and patent regimes

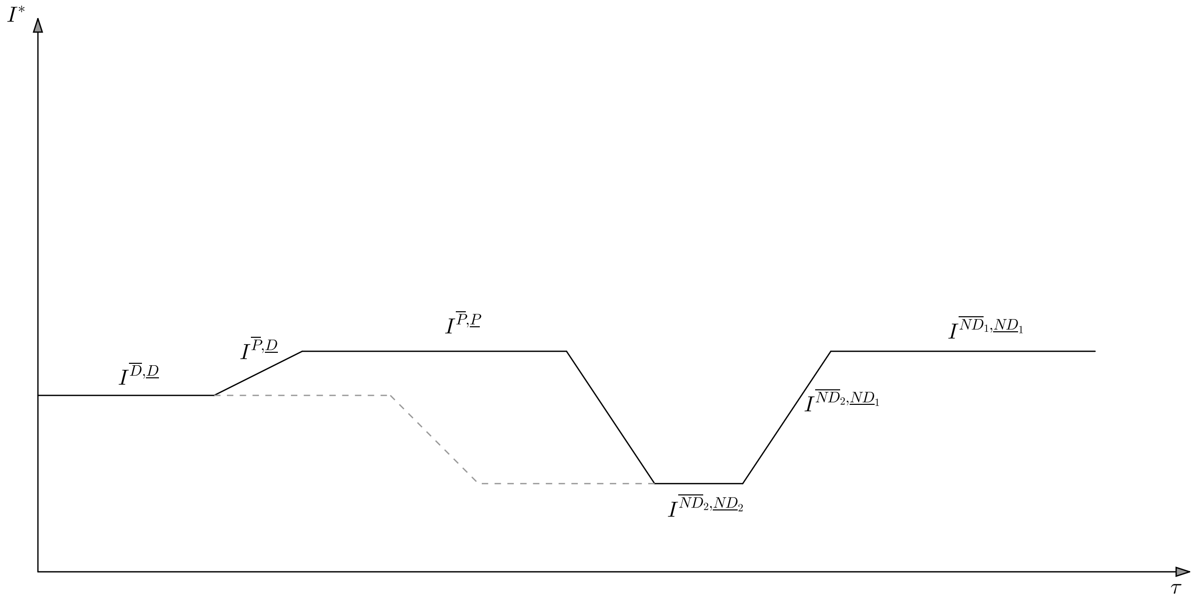


Figure 4.2.1: Private and social optimal investments under both PBR and patent regimes

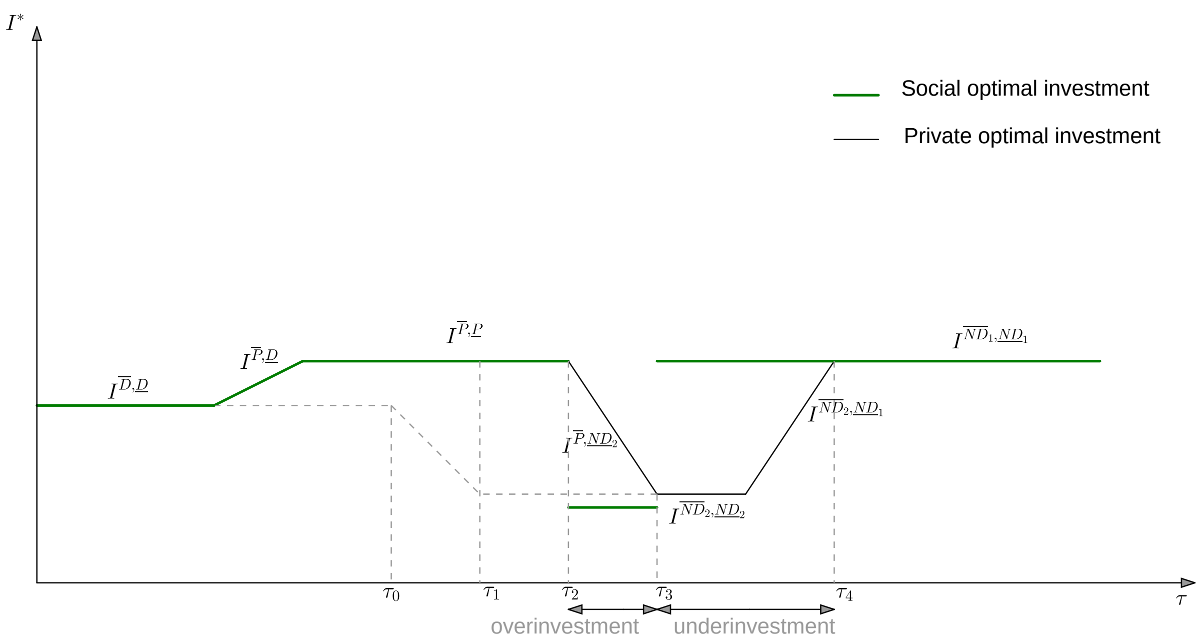


Figure 3.3: Seed producer strategies under both PBR and patent regimes

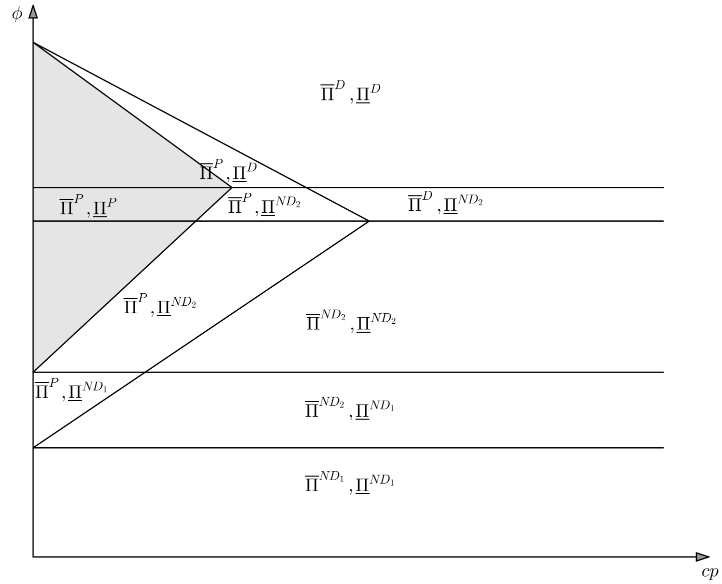


Figure 4.3: Private and social optimal investment under both PBR and patent regimes in (I, ϕ)

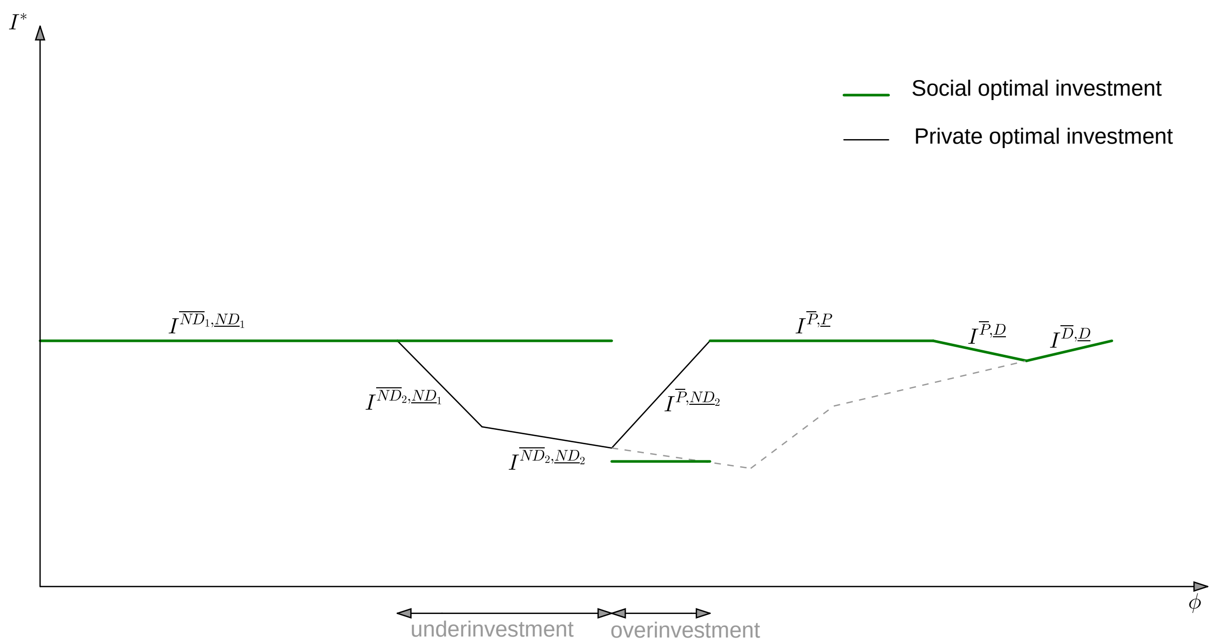


Figure 5.1: Incentives to innovate under a PBR regime

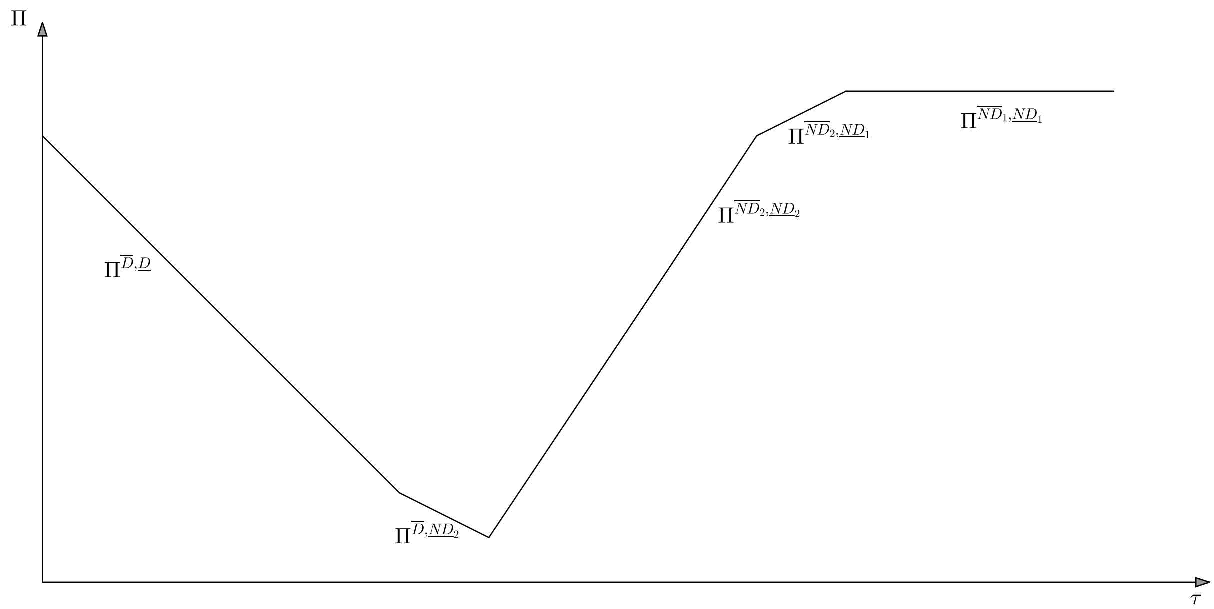


Figure 5.2: Incentives to innovate under both PBR and patent regimes

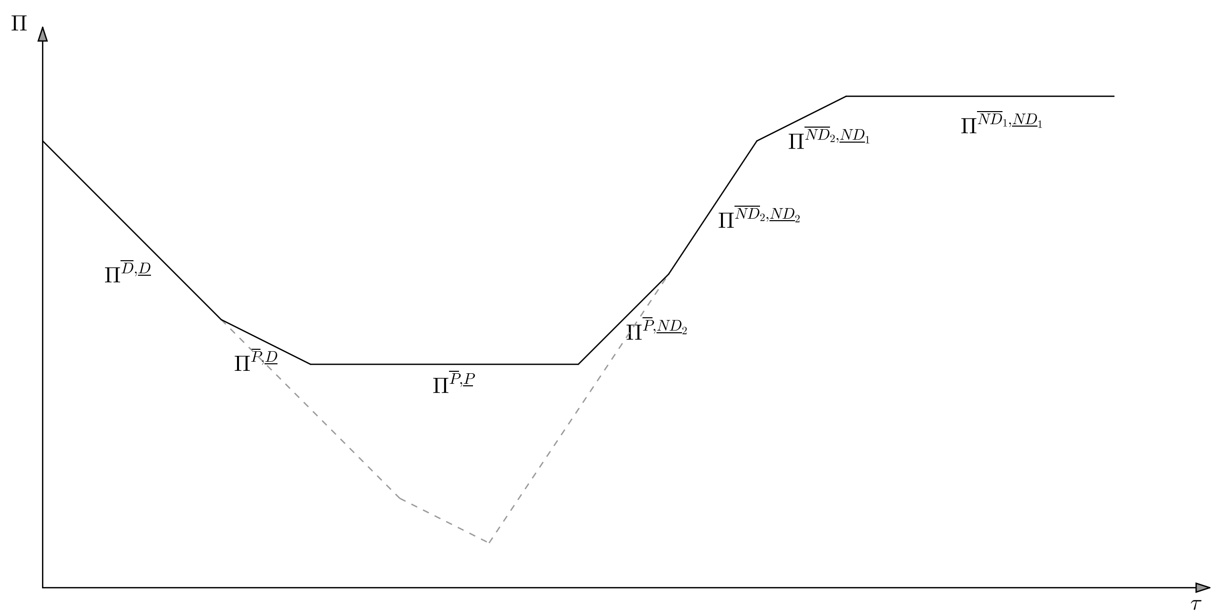


Figure 6.1: Welfare under a PBR regime

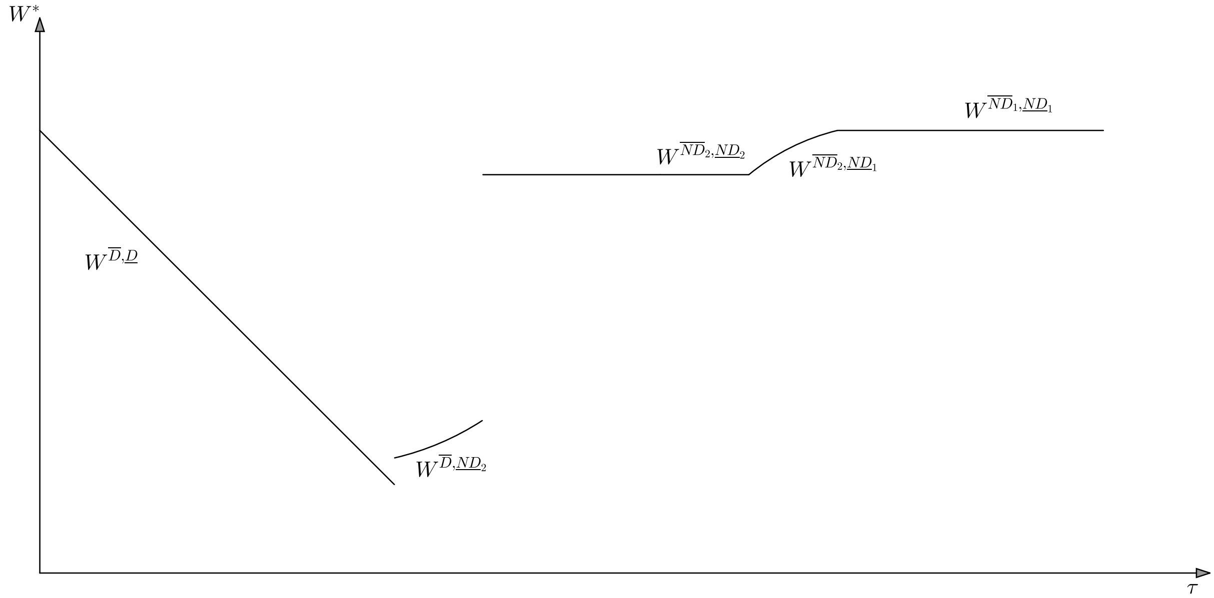
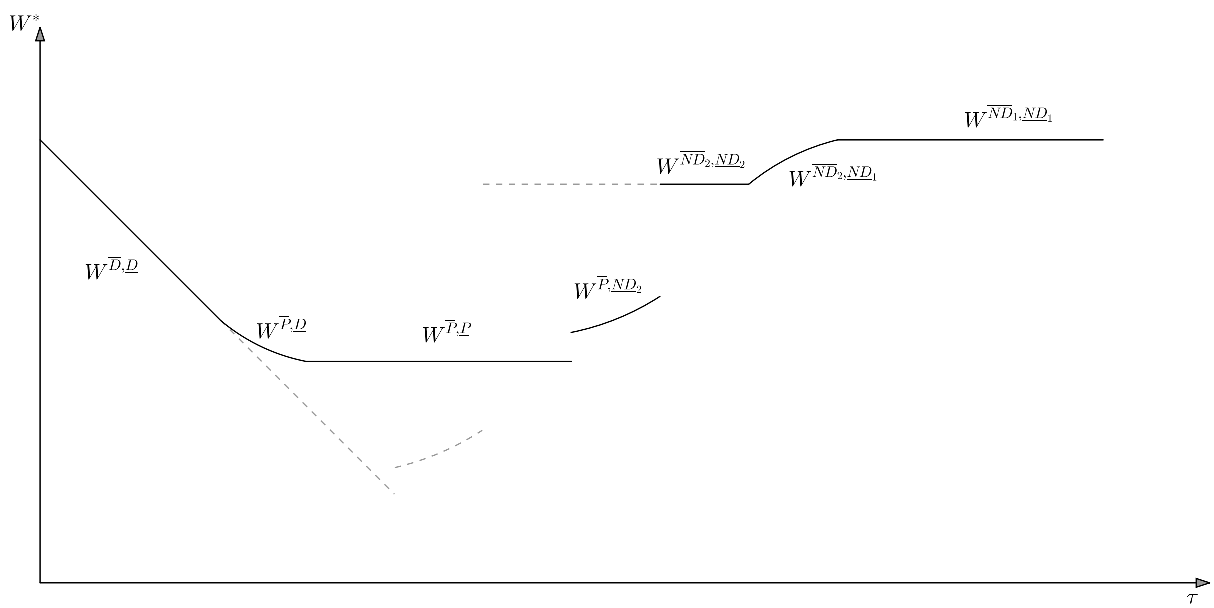


Figure 6.2: Welfare under both PBR and patent regimes



Appendix

A Price equilibrium under a PBR regime

When $\phi \geq \phi_1$, the seed producer can choose between non-durable good strategy 2 with prices $\{p_1^{ND}, p_2^{ND_2}\}$ which yields a payoff Π^{ND_2} and the durable good strategy with prices $\{p_1^D, p_2^D\}$ which gives a payoff Π^D. As long as $\Pi^{ND_2} > \Pi^D$ (respectively, $\Pi^{ND_2} \leq \Pi^D$) a non-durable good strategy (resp., a durable good strategy) will be adopted, which happens for $\phi < \phi_2$ (resp., for $\phi \geq \phi_2$) with ϕ_1 and ϕ_2 defined by (2) and (9). In a graph (τ, ϕ), represented in Figure 1 we find three distinct areas where $\phi_2 > \phi_1$.

B Choice between a PBR and a Patent

For a given innovation size θ, the seed producer can decide whether to protect his innovation with a patent or a PBR. He will patent as long as $\Pi^P > \Pi^j$ with $j = D, ND_1, ND_2$.

Figure 2.a. represents a configuration in which $c_P < (1-\lambda)(\theta\pi - \pi_0)/(2-\lambda)$. To determine this condition, we calculate the value of τ for which $\phi_2 = 1$, which is $2(\theta\pi - \pi_0)/(2-\lambda)$ and for which $\phi_1^P = 1$, which is $2(\theta\pi - \pi_0) - c_P$. Then, ϕ_2 evaluated at 1 is smaller than ϕ_1^P evaluated at 1 if $2(\theta\pi - \pi_0)/(2-\lambda) < 2(\theta\pi - \pi_0) - c_P$. This latter condition also insures that ϕ_2^P is smaller than ϕ_2 both evaluated at 1. It is also easy to check that for $\tau = 0$, $\phi_1 = \pi_0/\theta\pi < \phi_1^P = (\pi_0 + c_P)/\theta\pi < \phi_2 = (\theta\pi + \pi_0)/2\theta\pi < \phi_2^P = (\theta\pi - c_P)/\theta\pi < 1$.

Figure 2.b. corresponds to a situation where less patenting will occur as the patenting cost is higher, $c_P < (1-\lambda)(\theta\pi - \pi_0)/(2-\lambda)$ but with $c_P > (\theta\pi - \pi_0)/2$.

C Optimal investment levels

Before calculating the optimal levels of investment, we first define under what circumstances the seed producer will choose a pricing strategy for each innovation size $\underline{\theta}$ and $\overline{\theta}$.

PBR regime

In Figure 3.1. we represent the different areas where the producer chooses a durable good strategy and a non-durable good strategy. In order to have $\phi_2(\overline{\theta}) > \phi_1(\underline{\theta})$, we must have$(\overline{\theta}\pi + \pi_0)/(2\overline{\theta}\pi) > \pi_0/(\underline{\theta}\pi)$, and $\underline{\theta}\pi - \pi_0 > (\overline{\theta}\pi - \pi_0)/(2-\lambda)$. The first inequality is equivalent to having $\underline{\theta}\pi > (2\overline{\theta} - \underline{\theta})\pi_0/\overline{\theta}$, and the second one to having $\underline{\theta}\pi > (1-\lambda)\underline{\theta}\pi_0/((1-\lambda)\underline{\theta} - (\overline{\theta} - \underline{\theta}))$, with $(1-\lambda)\underline{\theta} - (\overline{\theta} - \underline{\theta}) > 0$. Therefore, as $(2\overline{\theta} - \underline{\theta})/\overline{\theta} < (1-\lambda)/((1-\lambda)\underline{\theta} - (\overline{\theta} - \underline{\theta}))$, the only conditions that are needed are

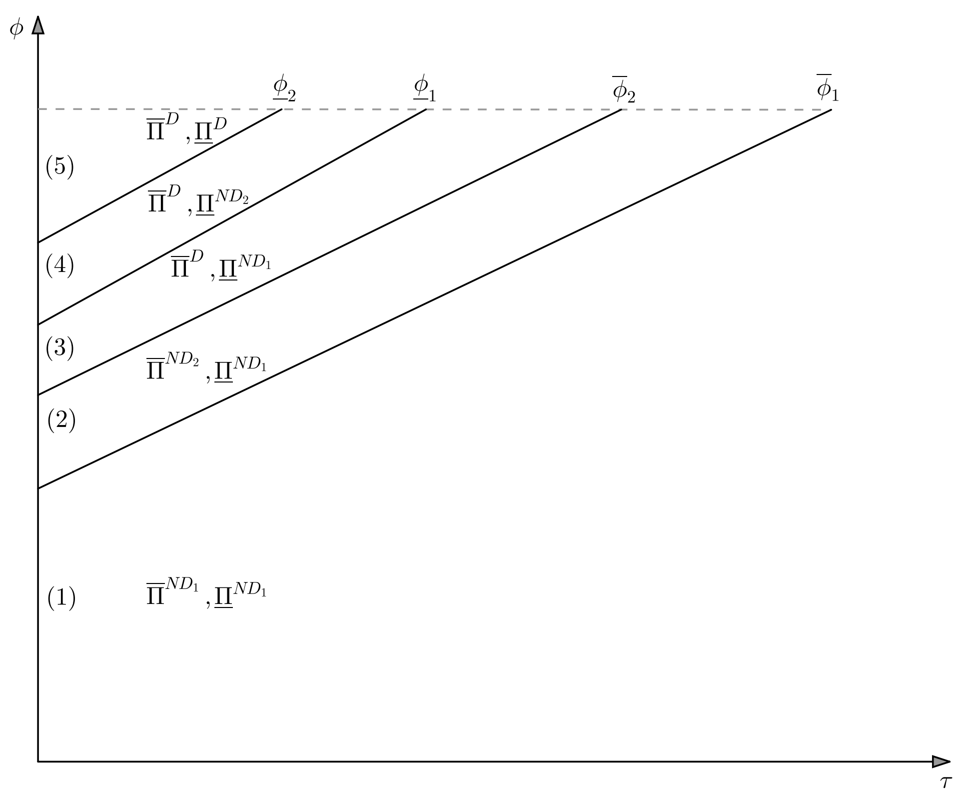
$$\overline{\theta} < (2-\lambda)\underline{\theta}, \tag{19}$$

and

$$\underline{\theta}\pi > \frac{(1-\lambda)\underline{\theta}}{(1-\lambda)\underline{\theta} - (\overline{\theta} - \underline{\theta})}\pi_0. \tag{20}$$

We combine these two assumptions to obtain that $\overline{\theta} < (2-\lambda)\underline{\theta} - (1-\lambda)\pi_0/\pi$. If this latter inequality is not satisfied, $\overline{\phi}_2 < \underline{\phi}_1$ as represented in Figure 3.1.1. This corresponds to the case where the large innovation is much larger than the small one. In this case the areas are different as there is an area in which the producer who has discovered a large innovation prefers to use a durable good strategy while if he has discovered a small one he will prefer to use a non-durable good strategy.

Figure 3.1.1: Seed producer strategies under a PBR regime with $\theta \in \{\underline{\theta}, \overline{\theta}\}$



In each area defined in Figure 3.1., we determine the investment decision. In area (1), the producer uses non-durable good strategy 1 for any innovation size, and thus he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^{ND_1} + (1-\mu(I))\underline{\Pi}^{ND_1} - I\},$$

which gives the following first order condition

$$\mu'(I)[2(\overline{\theta}-\underline{\theta})\pi] - 1 = 0.$$

We denote $I^{\overline{ND_1},\underline{ND_1}}$ the optimal investment level, which is independent of τ.

In area (2), the seed producer uses non-durable good strategy 1 for a small innovation and non-durable good strategy 2 for a large innovation and, then, chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^{ND_2} + (1-\mu(I))\underline{\Pi}^{ND_1} - I\},$$

which gives the first order condition

$$\mu'(I)[2(\overline{\theta}-\underline{\theta})\pi + \pi_0 + \tau - \overline{\theta}\phi\pi] - 1 = 0.$$

We denote $I^{\overline{ND_2},\underline{ND_1}}$ the optimal level of investment. This level of investment increases with τ. Indeed, if we totally differentiate the first order condition and we rearrange the terms, we find $dI/d\tau = -\mu''(I) > 0$, as $\mu''(I) < 0$.

At the threshold $\overline{\phi}_1$, $I^{\overline{ND_1},\underline{ND_1}}$ and $I^{\overline{ND_2},\underline{ND_1}}$ are equal for a tax $\tau = \overline{\theta}\phi\pi - \pi_0$. Below this tax level, the seed producer is in area (2) for an investment level ($I^{\overline{ND_2},\underline{ND_1}}$) lower than the investment level in area (1) ($I^{\overline{ND_1},\underline{ND_1}}$). However, the tax has a positive impact on the investment level.

In area (3), when the seed producer uses non-durable good strategy 2 for any size of the innovation, he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^{ND_2} + (1-\mu(I))\underline{\Pi}^{ND_2} - I\},$$

which gives the first order condition

$$\mu'(I)[(\overline{\theta} - \underline{\theta})\pi(2 - \phi)] - 1 = 0.$$

We denote $I^{\overline{ND}_2,\underline{ND}_2}$ the optimal level of investment, which does not depend on τ.

At the threshold $\underline{\phi}_1$, $I^{\overline{ND}_2,\underline{ND}_1}$ and $I^{\overline{ND}_2,\underline{ND}_2}$ are equal. In area (2), the tax level is between $\underline{\theta}\phi\pi - \pi_0$ and $\overline{\theta}\phi\pi - \pi_0$, as a consequence, $I^{\overline{ND}_2,\underline{ND}_1}$ is higher than $I^{\overline{ND}_2,\underline{ND}_2}$.

In area (4), the seed producer uses a durable good strategy for a large innovation and non-durable good strategy 2 for a small innovation, and thus chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^D + (1 - \mu(I))\underline{\Pi}^{ND_2} - I\},$$

which gives the first order condition

$$\mu'(I)[2(\overline{\theta} - \underline{\theta})\pi - \pi\overline{\theta}(1 - \phi) + \underline{\theta}\pi\phi - \pi_0 - \tau(2 - \lambda)] - 1 = 0.$$

We denote $I^{\overline{D},\underline{ND}_2}$ the optimal level of investment, which is decreasing in τ. If we totally differentiate the first order condition, we find that $dI/d\tau = \mu''(I)/(2 - \lambda) < 0$.

In area (5), the seed producer uses the durable good strategy for any size of the innovation and chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^D + (1 - \mu(I))\underline{\Pi}^D - I\},$$

which gives the first order condition

$$\mu'(I)[(1 + \phi)(\overline{\theta} - \underline{\theta})\pi] - 1 = 0.$$

We denote $I^{\overline{D},\underline{D}}$ the optimal investment level which does not depend on τ.

We then calculate the socially optimal levels of investment that solve

$$\max_I \{\mu(I)\overline{W} + (1 - \mu(I))\underline{W} - I\},$$

where $\overline{W}$ and $\underline{W}$ are determined in function of the pricing strategies chosen by the seed producer for large and small innovations. For instance, in area (1) in Figure 3.1., the socially optimal level of investment is solution of

$$\max_I \{\mu(I)\overline{W}^{ND} + (1-\mu(I))\underline{W}^{ND} - I\},$$

where $W^{ND} = 2\theta\pi$. We denote $I_W^{\overline{ND},\underline{ND}}$ the solution of this maximizing program. For each of the five areas in Figure 3.1., we calculate the different levels of socially optimal investments.

For each of the five areas in Figure 3.1. we summarize the profit and social welfare functions and the private and socially optimal levels of investment, as well as the comparison of the levels of investments in Table 2.

	Profits	Optimal Investment	Welfare	Socially optimal investment
Area 1	$\overline{\Pi}^{ND_1}, \underline{\Pi}^{ND_1}$	$I^{\overline{ND}_1,\underline{ND}_1}$	$\overline{W}^{ND}, \underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}} = I^{\overline{ND}_1,\underline{ND}_1}$
Area 2	$\overline{\Pi}^{ND_2}, \underline{\Pi}^{ND_1}$	$I^{\overline{ND}_2,\underline{ND}_1}$	$\overline{W}^{ND}, \underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}} = I^{\overline{ND}_1,\underline{ND}_1}$
Area 3	$\overline{\Pi}^{ND_2}, \underline{\Pi}^{ND_2}$	$I^{\overline{ND}_2,\underline{ND}_2}$	$\overline{W}^{ND}, \underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}} = I^{\overline{ND}_1,\underline{ND}_1}$
Area 4	$\overline{\Pi}^{D}, \underline{\Pi}^{ND_2}$	$I^{\overline{D},\underline{ND}_2}$	$\overline{W}^{D}, \underline{W}^{ND}$	$I_W^{\overline{D},\underline{ND}_2} < I^{\overline{D},\underline{ND}_2}$
Area 5	$\overline{\Pi}^{D}, \underline{\Pi}^{D}$	$I^{\overline{D},\underline{D}}$	$\overline{W}^{D}, \underline{W}^{D}$	$I_W^{\overline{D},\underline{D}} = I^{\overline{D},\underline{D}}$

Table 2: Results under a PBR regime

Patent and PBR regimes

When the producer can choose between a patent and a PBR, we represent the different areas in Figure 3.2. In the seven different areas we calculate the optimal level of investment chosen by the seed producer. In areas (1), (2) and (3), the results are similar to those we found before.

In area (4), the seed producer chooses a PBR for a small innovation and a patent for a large innovation. He then solves the following optimization program

$$\max_I \{\mu(I)\overline{\Pi}^P + (1-\mu(I))\underline{\Pi}_2^{ND} - I\},$$

which gives the first order condition

$$\mu'(I)[2(\overline{\theta}-\underline{\theta})\pi - \pi_0 + \underline{\theta}\pi\phi - \tau - c_P] - 1 = 0.$$

We denote $I^{\overline{P},\underline{ND}_2}$ the optimal level of investment. At the threshold $\overline{\phi}_1^P$, $I^{\overline{ND}_2,\underline{ND}_2}$ and

$I^{\overline{P},\underline{ND}_2}$ are equal. In area (4), the tax is included between $\underline{\theta}\phi\pi - \pi_0 - c_p$ and $\overline{\theta}\phi\pi - \pi_0 - c_p$, thus $I^{\overline{ND}_2,\underline{ND}_2}$ is higher than $I^{\overline{P},\underline{ND}_2}$. However, the tax has a negative impact on the investment.

If the seed producer decides to patent both types of innovation, in area (5), he solves

$$\max_I \{\mu(I)\overline{\Pi}^P + (1-\mu(I))\underline{\Pi}^P - I\},$$

which gives the first order condition

$$\mu'(I)[2(\overline{\theta} - \underline{\theta})\pi] - 1 = 0.$$

We denote $I^{\overline{P},\underline{P}}$ the optimal level of investment, which does not depend on τ.

At the threshold $\underline{\phi}_1^P$, $I^{\overline{P},\underline{ND}_2}$ and $I^{\overline{P},\underline{P}}$ are equal. Furthermore, $I^{\overline{P},\underline{P}}$ is equal to $I^{\overline{ND}_1,\underline{ND}_1}$ such that the incentive to innovate in area (5) are the greatest. Thus, $I^{\overline{P},\underline{P}}$ is greater than $I^{\overline{ND}_2,\underline{ND}_1}$, $I^{\overline{ND}_2,\underline{ND}_2}$ and $I^{\overline{P},\underline{ND}_2}$ except for the threshold value where $I^{\overline{P},\underline{P}}$ is equal to $I^{\overline{P},\underline{ND}_2}$.

In area (6), if the seed producer chooses a PBR for the small innovation and a patent for the large innovation, he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^P + (1-\mu(I))\underline{\Pi}^D - I\},$$

which gives the first order condition

$$\mu'(I)[(2\overline{\theta} - \underline{\theta}(1+\phi))\pi + \tau(1-\lambda) - c_P] - 1 = 0.$$

We denote $I^{\overline{P},\underline{D}}$ the optimal level of investment, which increases with τ. If we totally differentiate the first order condition, we find that $dI/d\tau = -\mu''(I)/(1-\lambda) > 0$.

At the threshold $\underline{\phi}_2^P$, $I^{\overline{P},\underline{P}}$ and $I^{\overline{P},\underline{D}}$ are equal. The tax has a positive impact on the incentive but in area (6) the value of the tax involves that the incentive to innovate in area (5) is greater than in area (6).

In area (7), if the seed producer prefers a PBR with a durable good strategy, he chooses I that solves

$$\max_I \{\mu(I)\overline{\Pi}^D + (1-\mu(I))\underline{\Pi}^D - I\},$$

which gives the first order condition

$$\mu'(I)[(1+\phi)(\overline{\theta}-\underline{\theta})\pi]-1=0.$$

We denote $I^{\overline{D},\underline{D}}$ the optimal level of investment, which does not depend on τ.

At the threshold $\underline{\phi}_2^P$, $I^{\overline{P},\underline{D}}$ and $I^{\overline{D},\underline{D}}$ are equal. For a ϕ lower (higher) than 1/2, $I^{\overline{ND}_2,\underline{ND}_2}$ is higher (lower) than $I^{\overline{D},\underline{D}}$. For a $\phi<1$, $I^{\overline{ND}_1,\underline{ND}_1}$ and $I^{\overline{P},\underline{P}}$ are higher than $I^{\overline{D},\underline{D}}$.

We then calculate the socially optimal levels of investment that solve

$$\max_I\{\mu(I)\overline{W}+(1-\mu(I))\underline{W}-I\},$$

as we have done before. We find the different levels of optimal investment, one for each of the seven areas in Figure 3.2.

For each of the seven areas in Figure 3.2. we summarize the profit and social welfare functions and the optimal level of investments in Table 3.

	Profits	Optimal Investment	Welfare	Socially Optimal Investment
Area 1	$\overline{\Pi}^{ND_1},\underline{\Pi}^{ND_1}$	$I^{\overline{ND}_1,\underline{ND}_1}$	$\overline{W}^{ND},\underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}}=I^{\overline{ND}_1,\underline{ND}_1}$
Area 2	$\overline{\Pi}^{ND_2},\underline{\Pi}^{ND_1}$	$I^{\overline{ND}_2,\underline{ND}_1}$	$\overline{W}^{ND},\underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}}=I^{\overline{ND}_1,\underline{ND}_1}>I^{\overline{ND}_2,\underline{ND}_1}$
Area 3	$\overline{\Pi}^{ND_2},\underline{\Pi}^{ND_2}$	$I^{\overline{ND}_2,\underline{ND}_2}$	$\overline{W}^{ND},\underline{W}^{ND}$	$I_W^{\overline{ND},\underline{ND}}=I^{\overline{ND}_1,\underline{ND}_1}>I^{\overline{ND}_2,\underline{ND}_2}$
Area 4	$\overline{\Pi}^{P},\underline{\Pi}^{ND_2}$	$I^{\overline{P},\underline{ND}_2}$	$\overline{W}^{P},\underline{W}^{ND}$	$I_W^{\overline{P},\underline{ND}_2}<I^{\overline{P},\underline{ND}_2}$
Area 5	$\overline{\Pi}^{P},\underline{\Pi}^{P}$	$I^{\overline{P},\underline{P}}$	$\overline{W}^{P},\underline{W}^{P}$	$I_W^{\overline{P},\underline{P}}=I_W^{\overline{ND},\underline{ND}}$
Area 6	$\overline{\Pi}^{P},\underline{\Pi}^{D}$	$I^{\overline{P},\underline{D}}$	$\overline{W}^{P},\underline{W}^{D}$	$I_W^{\overline{P},\underline{D}}=I^{\overline{P},\underline{D}}<I_W^{\overline{ND},\underline{ND}}$
Area 7	$\overline{\Pi}^{D},\underline{\Pi}^{D}$	$I^{\overline{D},\underline{D}}$	$\overline{\Pi}^{P},\underline{\Pi}^{P}$	$I_W^{\overline{D},\underline{D}}=I^{\overline{D},\underline{D}}<I_W^{\overline{ND},\underline{ND}}$

Table 3: Results under patent and PBR regimes

D Incentives to Innovate

We first consider the case in which the producer protects his innovation only with a PBR. We calculate his *ex ante* expected profit for each of the five areas of Figure 3.1.

In area (1), given the optimal investment $I^{\overline{ND}_1,\underline{ND}_1}$ that does not depend on τ, the *ex ante* expected payoff is

$$\Pi^{\overline{ND}_1,\underline{ND}_1}(I^{\overline{ND}_1,\underline{ND}_1}) = \mu(I^{\overline{ND}_1,\underline{ND}_1})2(\overline{\theta}-\underline{\theta})\pi + 2(\underline{\theta}\pi - \pi_0) - I^{\overline{ND}_1,\underline{ND}_1},$$

which does not depend on τ.

In area (2), given the optimal investment $I^{\overline{ND}_2,\underline{ND}_1}$ that increases with τ, the *ex ante* expected payoff is

$$\Pi^{\overline{ND}_2,\underline{ND}_1}(I^{\overline{ND}_2,\underline{ND}_1}(\tau),\tau) = \mu(I^{\overline{ND}_2,\underline{ND}_1})[\overline{\theta}\pi(2-\phi)-\pi_0+\tau]+(1-\mu(I^{\overline{ND}_2,\underline{ND}_1}))2(\underline{\theta}\pi-\pi_0)-I^{\overline{ND}_2,\underline{ND}_1}.$$

Thus, by differentiating the expected payoff function we obtain

$$\frac{d\Pi^{\overline{ND}_2,\underline{ND}_1}}{d\tau} = \frac{\partial\Pi^{\overline{ND}_2,\underline{ND}_1}}{\partial I}\frac{\partial I}{\partial\tau} + \frac{\partial\Pi^{\overline{ND}_2,\underline{ND}_1}}{\partial\tau}.$$

By using the envelop theorem the first part is equal to zero and thus

$$\frac{\partial\Pi^{\overline{ND}_2,\underline{ND}_1}}{\partial\tau} = \mu(I^{\overline{ND}_2,\underline{ND}_1}) > 0.$$

In area (3), given the optimal investment $I^{\overline{ND}_2,\underline{ND}_2}$ that does not depend on τ, the *ex ante* expected payoff is

$$\Pi^{\overline{ND}_2,\underline{ND}_2}(\tau) = \mu(I^{\overline{ND}_2,\underline{ND}_2})(\overline{\theta}-\underline{\theta})\pi(2-\phi) + \underline{\theta}\pi(2-\phi) - \pi_0 + \tau - I^{\overline{ND}_2,\underline{ND}_2}.$$

Thus, by differentiating the expected payoff function we obtain $\partial\Pi^{\overline{ND}_2,\underline{ND}_2}/\partial\tau = 1 > 0$.

In area (4), given the optimal investment $I^{\overline{D},\underline{ND}_2}$ that decreases with τ, the *ex ante* expected payoff is

$$\Pi^{\overline{D},\underline{ND}_2}(I^{\overline{D},\underline{ND}_2}(\tau),\tau) = \mu(.)[\overline{\theta}\pi(1+\phi)-2\pi_0-\tau(1-\lambda)]+(1-\mu(.))[\underline{\theta}\pi(2-\phi)-\pi_0+\tau]-I^{\overline{D},\underline{ND}_2}.$$

Thus, by differentiating the expected payoff function we obtain

$$\frac{d\Pi^{\overline{D},\underline{ND}_2}}{d\tau} = \frac{\partial\Pi^{\overline{D},\underline{ND}_2}}{\partial I}\frac{\partial I}{\partial\tau} + \frac{\partial\Pi^{\overline{D},\underline{ND}_2}}{\partial\tau}.$$

By using the envelop theorem the first part is equal to zero and thus

$$\frac{\partial \Pi^{\overline{D},\underline{ND_2}}}{\partial \tau} = -\mu(.)(1-\lambda) + (1-\mu(.)) = 1 - \mu(.)(2-\lambda).$$

The sign of this derivative depends on the value of $\mu(I^{\overline{D},\underline{ND_2}})$. Thus

$$\begin{aligned} \frac{\partial \Pi^{\overline{D},\underline{ND_2}}}{\partial \tau} &< 0 \text{ if } \mu(I^{\overline{D},\underline{ND_2}}) < 1/(2-\lambda) \\ \frac{\partial \Pi^{\overline{D},\underline{ND_2}}}{\partial \tau} &> 0 \text{ if } \mu(I^{\overline{D},\underline{ND_2}}) > 1/(2-\lambda) \end{aligned}$$

In area (5), given the optimal investment $I^{\overline{D},\underline{D}}$ that does not depend on τ, we calculate the *ex ante* expected profit

$$\Pi^{\overline{D},\underline{D}}(\tau) = \mu(I^{\overline{D},\underline{D}})(\overline{\theta} - \underline{\theta})\pi(1+\phi) + \underline{\theta}\pi(1+\phi) - 2\pi_0 - \tau(1-\lambda) - I^{\overline{D},\underline{D}}.$$

Thus, by differentiating the expected payoff function we obtain $\partial \Pi^{\overline{D},\underline{D}}/\partial \tau = -(1-\lambda) < 0$.

If we consider the functional form $\mu(I) = 1 - exp^{-I}$, in area (4), we find that $\partial \Pi^{\overline{D},\underline{ND_2}}/\partial \tau < 0$. In order to represent these functions in a graph (Π, τ), we use this functional form. We represent these functions in Figure 5.1.

We now consider the case where both patent and PBR systems coexist and calculate the *ex ante* expected profit of the seed producer for each of the seven areas of Figure 3.2. In areas (1), (2), (3) and (7), the expected payoffs have been calculated above and are respectively $\Pi^{\overline{ND_1},\underline{ND_1}}$, $\Pi^{\overline{ND_2},\underline{ND_1}}$, $\Pi^{\overline{ND_2},\underline{ND_2}}$ and $\Pi^{\overline{D},\underline{D}}$.

In area (4), the expected payoff evaluated at $I^{\overline{P},\underline{ND_2}}$ is

$$\Pi^{\overline{P},\underline{ND_2}} = \mu(I^{\overline{P},\underline{ND_2}})\overline{\Pi}^P + (1 - \mu(I^{\overline{P},\underline{ND_2}}))\underline{\Pi}^{ND_2} - I^{\overline{P},\underline{ND_2}}.$$

By using the envelop theorem, we calculate the derivative of $\Pi^{\overline{P},\underline{ND_2}}$ with respect to τ

$$\frac{\partial \Pi^{\overline{P},\underline{ND_2}}}{\partial \tau} = (1 - \mu(I^{\overline{P},\underline{ND_2}})) > 0.$$

In area (5), the expected payoff evaluated at $I^{\overline{P},\underline{P}}$ is

$$\Pi^{\overline{P},\underline{P}} = \mu(I^{\overline{P},\underline{P}})\overline{\Pi}^P + (1 - \mu(I^{\overline{P},\underline{P}}))\underline{\Pi}^P - I^{\overline{P},\underline{P}},$$

which does not depend on τ.

In area (6), the expected payoff evaluated at $I^{\overline{P},\underline{D}}$ is

$$\Pi^{\overline{P},\underline{D}} = \mu(I^{\overline{P},\underline{D}})\overline{\Pi}^{P} + (1-\mu(I^{\overline{P},\underline{D}}))\underline{\Pi}^{D} - I^{\overline{P},\underline{D}}.$$

By using the envelop theorem, we calculate the derivative of $\Pi^{\overline{P},\underline{D}}$ with respect to τ

$$\frac{\partial \Pi^{\overline{P},\underline{D}}}{\partial \tau} = -(1-\mu(I^{\overline{P},\underline{D}})(1-\lambda) < 0.$$

By using the same functional form for $\mu(I)$ we represent the different expected payoff functions in Figure 5.1.

E Welfare analysis

We calculate the total expected welfare evaluated at the private optimal levels of investment.

Under a PBR regime only, we again use the five different areas in Figure 3.1. and the corresponding private investment levels reported in table 2. For instance, in area (1), we calculate the total expected welfare as

$$W^{\overline{ND}_1,\underline{ND}_1} = \mu(I^{\overline{ND}_1,\underline{ND}_1})2(\overline{\theta}-\underline{\theta})\pi + 2\underline{\theta}\pi - I^{\overline{ND}_1,\underline{ND}_1}.$$

As $I^{\overline{ND}_1,\underline{ND}_1}$ does not depend on τ, $\overline{W}^{\overline{ND}_1,\underline{ND}_1}$ is also not depending on τ.

In area (2), the total expected welfare is

$$W^{\overline{ND}_1,\underline{ND}_1} = \mu(I^{\overline{ND}_2,\underline{ND}_1})2(\overline{\theta}-\underline{\theta})\pi + 2\underline{\theta}\pi - I^{\overline{ND}_2,\underline{ND}_1}.$$

The optimal investment $I^{\overline{ND}_2,\underline{ND}_1}$ increases with τ, and thus

$$\frac{\partial W^{\overline{ND}_1,\underline{ND}_1}}{\partial \tau} = \frac{\partial I^{\overline{ND}_2,\underline{ND}_1}}{\partial \tau}(\mu'(I^{\overline{ND}_2,\underline{ND}_1})2(\overline{\theta}-\underline{\theta})\pi - 1) > 0,$$

as $\mu'(I^{\overline{ND}_2,\underline{ND}_1})2(\overline{\theta}-\underline{\theta})\pi - 1 > 0$.

For each area we calculate the expected welfare evaluated at the optimal levels of investment. We use the functional form $\mu(I) = 1 - exp^{-I}$ and Mathematica to represent Figure 6.1.

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