Intellectual Property Rights Regimes in the Plant Breeding Sector: Comparing Plant Breeders' Rights and Patents using Monte Carlo Simulation

ERASMUS UNIVERSITY ROTTERDAM
Erasmus School of Economics
Department of Economics

Supervisor: Prof. dr. H.P.G. Pennings

Name: Anne Albert van der Galiën
Exam number: 386151
E-mail address: 386151ag@eur.nl; annealbert@live.nl

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Anne Albert van der Galiën

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Abstract

This study explores how different IPR regimes, specifically the patent approach and the Plant Breeders' Rights (PBR) approach, affect market structure and consumer satisfaction in the plant breeding sector. It does so by developing a Monte Carlo simulation model of sequential and cumulative innovation. The results show that under a patent system, the industry under consideration has some monopolistic tendencies, whereas under a PBR approach such monopolistic tendencies are observed to a significantly lesser extent. Also, consumer satisfaction is higher under a PBR approach.

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I. Introduction

The plant breeders industry is a capital-intensive sector that invests heavily in developing new and better plant varieties. Plant varieties can be improved by developing resistance for certain illnesses, developing the ability to grow in very dry or very wet areas, or developing other beneficial features for producers or consumers. Like in other industries with a heavy focus on research and development, intellectual property is an important factor with regards to the efficiency of the overall industry.

In the Netherlands, but also in Germany and France, amongst others, the intellectual property rights consist foremost of Plant Breeders' Rights. This is in contrast to the situation in the United States, for example, where a patenting approach is employed in this industry. The Plant Breeders' Rights approach gives the exclusive right of direct commercial use to the breeder who developed the plant variety. However, the seeds of the plant may still be used by other breeders in order to improve their product. More specifically, Plant Breeders' Rights grant property rights on plants, but not on their seeds, which can then be used freely by other companies or researchers. Proponents of this approach often emphasize that in this way, the development of new and better plant varieties is stimulated, while not negatively affecting the level of investments in research and development because of the offered protection. In the patenting approach, other breeders are not allowed to use the seeds of patented plant varieties in order to develop new varieties. According to proponents of the Plant Breeders' Rights (hereafter also referred to as PBR) approach, this limits the overall development of plant varieties.

In Europe, the patenting approach is starting to become more common, which is a controversial development. Plant breeders are afraid that their industries based on Plant Breeders' Rights will be negatively affected by this practice of patenting plant varieties, and various groups and persons worry about the loss of biodiversity that the patenting approach might induce. At first, patenting plants seemed to be impossible in Europe, for the European Patent Convention, in Article 53(b) EPC, states that European patents will not be granted in respect of "plant or animal varieties or essentially biological processes for the production of plants or animals[…]". Case law by the Enlarged Board of Appeal (EBoA), however, decided that plants are in principle patentable, first in G1/98, and later clarified and confirmed in G2/12 and G2/13.

The aim of this paper is to study how the different intellectual property rights (IPR) approaches affect the plant breeders industry. More specifically, this paper will develop simulation models of the plant breeding industry that employ either the patenting or the Plant Breeders' Rights approach. Using those models, the effect of the different IPR regimes on market structure and consumer satisfaction will be studied. In order to do so, this study will be guided by the following research question:

To what extent does employing Plant Breeders' Rights differ in its consequences on market structure and consumer satisfaction from employing patents as IPR regime in the plant breeding sector?

There does not exist much literature on the topic yet. There is some empirical literature on the effects of a PBR system (see e.g. Jaffe & van Wijk, 1995), and there is a study of Wageningen University on the difference between a patents- or PBR system in the Netherlands, conducted upon request of the Dutch ministry of Agriculture, Nature, and Food Quality (Louwaars et al., 2009). Moschini and Yerokhin (2008) develop a quality ladder model of sequential innovation which suggests that firms generally prefer a patenting system over a PBR system. Lence et al. (2016) develop a simulation model which shows that there exist rationales for both the PBR (or Plant Variety Protection, as Lence et al. call it) approach as well as the patenting approach. However, none of this research addresses the effect of the IPR regime employed on market structure and consumer satisfaction (though Lence et al. (2016) do address societal welfare). This paper aims to fill this gap in the literature.

The social relevance of the topic lies in the fact that the plant breeding industry is co-responsible for one of the most basic human necessities: a stable and sufficient supply of food. Hence, an IPR regime that helps to establish or sustain such a stable and sufficient supply of food is desirable.

This paper is structured as follows. In the next section, some related literature will be discussed. This section will focus on the paper by Moschini and Yerokhin (2008) and the paper by Lence et al. (2016). Afterwards, the motivation for the employed methodology of this paper is discussed. Subsequently, the model is described in detail, and some aspects of the model will be discussed. Then, the results of the simulations will be presented. The paper finishes with a discussion of the results in relation to policy and related literature, and a conclusion in which the research question will be answered. Limitations of this study and suggestions for further research are also provided.

II. Related literature

The *raison d'être* of intellectual property rights is the problem of free-riding associated with the competitive provision of innovations. Economic analyses suggests that intellectual property rights can prevent (immediate) free-riding of competitors on innovations that result from research and development efforts of a given firm (see Scotchmer (2004) for an overview of such literature). However, introducing intellectual property rights only provides a second-best solution for this free-riding problem, since it creates temporary monopoly power for the firm having intellectual property rights on a given innovation (Arrow, 1962). Thus, the discussion on to what extent intellectual property rights should be provided boils down to a discussion on the trade-off between preventing free-riding problems and restricting the monopoly power resulting from granting intellectual property rights. In Nordhaus' (1969) words, intellectual property rights provide dynamic gains by incentivizing firms to undertake research and development efforts, but result in static losses because the monopoly power results in a inefficiently limited use of innovations. Those static losses are especially problematic in the context of sequential innovation, where intellectual property rights may prevent other firms from engaging in follow-up research and development by prohibiting them to use previous innovations that are necessary for such follow-up R&D.

Since the plant breeding sector is characterized by sequential innovation, static losses form an important issue for the innovativeness of the sector. Various countries try to counter this issue by providing a breeders exemption, which allows firms to incorporate previous innovations in plant variety traits in their own plant varieties, but prohibits firms from imitating plant varieties of other firms. This breeders exemption sparked some research, of which two papers are most relevant for the study this paper performs. In one paper, a game-theoretic quality ladder model is developed by Moschini and Yerokhin (2008), and in the other paper Lence et al. (2016) develop a deterministic simulation model.

In the game-theoretic quality ladder model introduced by Moschini and Yerokhin (2008), a cumulative and sequential R&D contest in an infinite-horizon setting takes place, with two firms aiming to innovate on a single good in order to become 'leader'. The leader position allows a firm to produce and sell its product, whereas the firm in the 'follower' position cannot sell its product. Moschini and Yerokhin (2008) develop two versions of the model, one with and one without a research exemption[1]. In both versions of the model, there are two games, namely an initial game, and an improvement game. Two identical firms start with the initial game, in which both engage in an R&D contest in which a firm is successful with a certain probability. Only one firm can win the contest in this initial game, after which the improvement game starts. Here, the firms are not identical since one became the leader, and the other became the follower. In the version of the model without research exemption, the follower cannot take part in the R&D contest anymore, and the improvement game reduces to an optimization problem for monopolists. In the version with research exemption, the follower can still take part in the R&D contest and try to become the leader (which is attractive because of the associated positive payoffs, as opposed to the follower position where a firm does not receive payoffs), whereas the leader can take part in the R&D contest in order to add innovations to its current product, thereby increasing its payoffs. Next to aiming to increasing its payoffs, a leader will participate in the R&D contest in order to preserve its leadership position. Solving the model, Moschini and Yerokhim obtain the following results: firms, *ex ante*, always prefer the IPR regime without research exemption, as this regime results in higher expected payoffs than the regime with research exemption. From the point of view of social welfare, which IPR regime is preferred depend on the costs of R&D. When R&D costs are low, an IPR regime with research exemption results in most social welfare, whereas for cases with high R&D costs the regime without research exemption is preferred.

Main differences between the study of Moschini and Yerokhim (2008) and this study include, besides the difference in modelling techniques, the time setting and heterogeneity in firms, consumers, and products. Moschini and Yerokhim's model includes an infinite horizon, whereas the model developed in this paper assigns a limited

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[1] The term 'research exemption' denotes the same as 'breeders' exemption', but the first term is used in the Plant Variety Protection (PVP) act, whereas the second term is used in the Plant Breeders' Rights approach. Essentially, the PVP and the PBR approach are very similar.

expected lifetime for each product. This results in lower expected payoffs for the firms in this model relative to those in Moschini and Yerokhim's model. Also, whereas in Moschini and Yerokhim's model there exists one good, one type of consumer, and one or two firms, in the model of this paper there exist multiple goods, heterogeneous consumer groups, and multiple firms. Another important difference is the different focus of the study. Moschini and Yerkohim (2008) focus mainly on incentives for firms, whereas the model in the present paper focusses on consumer satisfaction and market structure.

Lence et al. (2016) aim to examine the different incentive structures generated by the PBR and patent approach and the impact of those incentive structures on social welfare. To do so, they develop a deterministic infinite-horizon dynamic model consisting of a number of identical private firms. There exist three distinct types of periods in their model, one in which research is done, another one where the firm can exclusively reap the benefits of the research it performed, and a third period, in which a firm faces competition of other firms who adapted the firm's plant variety in case there is a breeders exemption, but do not face competition otherwise. R&D projects are always successful, and there is always room for more innovation. A firm develops its own genetic stock, which is the aggregate of the results of previous R&D projects. Increasing genetic stocks decreases the research costs of firms. Access to other firm's genetic stocks also reduces research costs, and happens as soon as an innovation is introduced in case there is a breeders exemption, never happens in case of trade secrets, and happens after patent protection expires in the case of patents without breeders exemption. Firm revenues increase at a decreasing rate with successful R&D projects, and are negatively affected by successful R&D projects of competitors. In the model, firms simultaneously optimise their research decisions. Besides the effects on firms, the model also incorporates social welfare in the analysis by including a measure of social welfare based on a representative consumer. The utility function of the representative consumer increases at a decreasing rate with aggregate improvements (which result from R&D projects), though the benefits of those improvements decay over time. The authors vary the time it takes to do research, the number of periods over which a firm can reap the benefits of its R&D projects, the number of periods it takes before firms can use genetic stocks of competitors, and the extent to which firms can use the genetic stock of other firms. The results indicate that with time-consuming and specific research with a long expected lifetime of the improved variety, and when the research programme opens up avenues for new research, patents is the optimal IPR regime. An IPR regime with breeders exemption dominates when the type of research is straightforward and applicable across many firms, improved varieties have a short expected commercial life span, and with research programmes that make incremental gains.

The approach of Lence at al. (2016) differs from the present paper in a number of important respects. First, their model is deterministic, whereas the model developed in the present paper has stochastic elements. Second, in the model of Lence et al., there exists a general stock of genetic improvements that yields utility to a representative consumer, whereas in the present model heterogeneous consumer groups exist that prefer various plant variety traits to be developed to different extents. This implies that in the present model, there is not necessarily room for more innovation, whereas there always is room for innovation in the model introduced by Lence et al. Also, genetic stocks do not decay over time in the model of the present paper, whereas this does happen in Lence et al. While realistic, due to the setup of the model introduced in the present paper, adding decay would not change the results of the model. A last main difference is the focus of the model: where Lence et al. (2016) focus on social welfare and firm revenues, the model introduced in this paper focusses on consumer satisfaction and market structure.

III. Motivation for the employed methodology

When one wants to construct a model involving multiple consumer groups, a considerable number of firms, and non-linear stochastic elements, the model becomes too complex to solve analytically. This is one of the reasons why economic models, e.g. the model of Moschini and Yerokhim (2008) discussed in the related literature, often involve only a limited number of firms or consumer groups. While such simplifications do make it feasible to study complex problems or industries to some extent, they could ignore important effects that may arise as a result of introducing more complexity. Opting to solve a model using simulations, instead of analytically, opens up possibilities for including complexity. This is the main reason why this paper employs Monte Carlo simulation techniques. A second reason is that analytically solving a model with stochastic elements does not yield too much insight about possible behaviours of the model over time, in case the model is fairly complex. This is due to path dependency, which arises most notably in complex systems. Using Monte Carlo simulation techniques allows one to incorporate path dependency, and hence track the possible behaviours of a complex model over time.

IV. Model outline

In order to study the differences between an industry under a Plant Breeders' Rights system and an industry under a patent system, one model for each industry is developed. The models are largely similar, except that in the PBR model firms can make use of a breeders' exemption, whereas in the patent model the firms cannot.

General description

The general working of the models is as follows. There are ten consumer groups in the model. Those consumer groups have different preferences, distributed over the five different traits that plant varieties have. Those different traits can be interpreted as the extent of drought resistance, resistance against certain diseases, suitability for certain climates, and so on, that a plant variety may possess. Consumer preferences are measured by an integer number. For example, a certain consumer group may have a preference of five for a certain trait, whereas another consumer group may have a preference of three for the same trait. The value of the preference reflects to what extent a consumer group desires a trait to be developed. Consumer preferences may change over time according to a stochastic process.

The extent to which a trait is developed in a plant variety is measured in the same way, that is, it is also measured by an integer number. This number determines to what extent the preferences of a certain consumer group are satisfied. However, this extent to which a consumer preference is satisfied is limited by the value of the consumer preference itself. That is, if one consumer group has a preference of five for a certain trait, and another consumer group has a preference of three for this trait, a plant variety that has a trait value of four for that trait satisfies the consumer preferences of the first group with a value of four, but the consumer preferences of the second group with a value of only three. The extent to which a trait is developed is also referred to as the number of innovation steps.

Firms can develop traits of their plant varieties by engaging in research projects. In the PBR model, firms can make use of the breeders exemption to 'catch up' with certain traits. This means that a firm can add a trait developed by another firm to its own plant variety. This type of research is risk-free, meaning that catching up with a certain trait never fails. Besides this 'catching up', a firm can engage in 'regular' investment by trying to develop certain traits further. How successful such regular investment is, is determined by a stochastic process, which determines whether zero, one, or two innovation steps are achieved (i.e., whether the value of the trait of the firm's plant variety increases by zero, one or two). In the patent model, only this last type of investment is available for firms. Firms compute expected profits as well as values to consumers (i.e., to what extent consumer preferences are satisfied) of various possible research projects, and subsequently choose to invest in the research project that yields the highest expected profit. Expected profits are based on costs and payoffs, where costs are the investment costs and the payoffs depend on the additional value to consumers that a firm can offer compared to the competition. Every year, a company can choose a new research project to invest in. A research project has a duration of multiple years, depending on which type of research project is chosen.

The type of competition assumed throughout the paper is as follows. Consumers always buy the good that best satisfies their preferences, conditional on that the price per additional innovation step of a plant variety compared to the competition does not exceed the value to consumers of one innovation step. This implies that firms can only compete on quality (interpreted as extent of development of the plant variety), and can charge a maximum price per innovation step ahead of the competition. Hence, competitors cannot undercut prices, which is in line with the usually rather low price elasticity of plant variety seeds due to the seed price being only a small part of the total production costs of plants themselves (Louwaars et al., 2009).

Simulation settings

The models are simulated over a period of 100 years, which is deemed sufficient for the differences between the PBR and the patent model to arise clearly. The time step of the simulation is always one year, meaning that every year, the model is simulated again. Every model is simulated ten times, after which averages will be taken and used for analysis in this paper.

Table 1: parameters of the model

Name	**Description**	**Value**
value	Value of one innovation step	30/40/50
costs_reg	Costs of a 'regular' investment	100
costs_cu*	Costs of a 'catching up' investment	25%/50%/75% of costs of a regular investment
success	Determines the amount of innovation steps made via a research project. This is determined via a truncated log-normal distribution with mean 1, standard deviation 0.5, and minimum and maximum of 0 and 2.49 respectively.	Probability of zero innovation steps: ~11% Probability of one innovation step: ~76% Probability of two innovation steps: ~12%
pva_factor (reg, cu*, cureg*)	Factor for calculating the present value of expected annuities flowing from the result of a research project (also: Annuity Factor)	Depends on the expected lifetime of the new product, the interest rate, and the duration of the research project (see entries below). Formula: $\delta = \frac{1-(1+r)^{exp\_lifetime}}{r((1+r)^{rp\_dur})}$ where rp_dur denotes the duration of the research project which can differ per type of research project ('regular', 'catching up', or both)
exp_lifetime	Expected lifetime of a product	6 years
rpreg_dur	Duration of a 'regular' research project	6 years
rpcu_dur*	Duration of a 'catching up' research project	3 years
r	The interest rate	5%/10%
changes_cons_pref	A sub-model creating changes in consumer preferences. Determined via a truncated log-normal distribution with mean 0.5, standard deviation 1, and minimum and maximum of 0 and 4.99 respectively. Calculated for every trait per consumer group, rounded down.	Probability of no change in preference: ~89% Probability of one step change in preference: ~7% Probability of two steps change in preference: ~2% Probability of three steps change in preference: ~1% Probability of four steps change in preference: ~0.5%
n/a	Number of (identical) firms	10
n/a	Starting capital per firm	500
n/a	Number of traits per plant	5
n/a	Number of consumer groups	10

Notes: xx/yy/zz indicates that this parameter will be varied in order to examine the direction of its effect on the output of the models.

Parameters

The model consists of a number of parameters, and a script that determines the firms' investment decisions and payoffs and stores information about research projects, payoffs, consumer preferences, et cetera. Information on the various parameters employed is displayed in table 1. An asterisk indicates that a parameter is only used in the PBR model.

The value of the parameters indicating the value of an innovation step or the value of investment costs are not realistic, however, for interpreting the results of the model the *ratio* of the value relative to the investment costs is important. The number of firms, number of traits per plant variety, and number of consumer groups are also not intended to be an accurate representation of reality. Instead, they are intended to resemble the heterogeneity in traits and consumer preferences, whereas the number of firms are deemed sufficient to analyse the effect of the different IPR regimes on market structure.

Script

First, the script for the PBR model will be discussed. Afterwards, I will discuss how the patent model deviates from the PBR model.

Matrices

In order to store and manipulate data on firms, research projects, existing plant varieties, and consumer preferences, a number of matrices are generated first.

The consumer preference matrix stores information about the preferences of each of the ten consumer groups for all of the five traits, and hence forms a 10x5 matrix. Consumer preferences change according to the stochastic process described in table 1, which allows for preferences to generally change slowly, but sometimes change more sharply (due to some sudden exogenous shock, e.g. in climate). Changes in preferences happen every six years. This period is chosen because too fast changing consumer preferences would decrease the expected lifetime of a product considerably (the lifetime of a plant variety is usually between three and seven years (Louwaars et al., 2009)).

The firms matrix stores information about a firms accumulated capital. Its capital is increased by payoffs from existing plant varieties, and decreased by investment costs.

There is a separate matrix that stores information about research projects. Specifically, it stores information on which firm runs the research project, at which consumer group it is aimed, which trait is caught up with (if applicable), which trait is researched (if applicable), the costs and duration of the research project, and the trait values of the existing plant variety that the firm aims to improve.

Furthermore, there is a matrix that stores existing plant varieties per firm. For every consumer group, a firm can have one plant variety. The matrix stores information on the trait values of each existing plant variety per consumer group per firm.

Another matrix stores information on which plant varieties serve the different consumer groups. Specifically, it stores the trait values of the relevant plant variety and which firm is the owner of that plant variety.

A couple of matrices are generated based on the above matrices. Those matrices are used to calculate e.g. the extent to which a plant variety serving a given consumer group satisfies their preferences, which consumer group has the most room for innovation, and the maximum trait values of existing plant varieties in the industry.

Processing current research projects

After generating and calculating the matrices described above, the model continues to process the currently running research projects. For unfinished research projects, the remaining duration is decreased by one year. For finished research projects, the script determines the value of the traits of the new plant variety. For 'catching up' investments, there is no risk of failed research; the trait that is caught up with simply increases to the maximum value of that trait in the industry. For 'regular' investments, the success of the research project is determined according to the stochastic process described in table 1. Subsequently, the script verifies whether the new plant variety offers more value to consumers than the plant varieties currently in the market for the relevant consumer group, and sets this new plant variety as from now on serving the relevant consumer group if this is the case.

Determining investment decisions

After the current research projects are processed, the actual investment decision making process of each firm is modelled. Two important concepts in this process are the (expected) value to consumers of a certain plant variety or research project, and the expected value of a research project to a firm. The functional form of the (expected) value to consumers of a certain plant variety or research project is as follows:

$$\varphi_{cg,k} = \sum_{l=1}^{5} \min(\gamma_{cg,l}, k_l), \tag{1}$$

where $\varphi_{cg,k}$ denotes the (expected) value to consumer group cg of plant variety or research project k. This (expected) value is equal to the sum of the (expected) values of different traits l of plant variety or research project k, in so far the value of trait l does not exceed the consumer preference of consumer group cg for trait l (denoted by γ). This last condition is necessary because for a consumer group that has a preference of, say, six for a given trait, developing this trait further than six does not yield additional satisfaction of consumer preferences. Note that (expected) value to consumers is not measured in monetary terms, but by to what extent consumer preferences are satisfied.

The functional form of the expected value of a research project k to firm i is as follows:

$$\mu_{i,k} = -\tau_k + \delta\omega(\max(\varphi_{cg,k} - \theta_{cg}, 0)), \tag{2}$$

where $\mu_{i,k}$ denotes the expected value to firm i of research project k. The first term, $-\tau_k$, denotes the investment costs, whereas the second term denotes the present value of the expected payoffs of the research project. The expected payoffs are determined by how much more consumer value a firm can offer compared to its competitors (denoted by $\varphi_{cg,k} - \theta_{cg}$ and having a minimum value of zero[2]) multiplied by the value to consumers of one innovation step, denoted by ω, and multiplied by the annuity factor δ. The computation of annuity factor δ can be found in table 1. The expected value to consumers offered by the competition (θ_{cg}) is the weighted average of possible outcomes of relevant research projects (i.e., research projects aimed at consumer group cg) and the plant variety currently serving consumer group cg.

The decision-making part of the script starts with checking for a firm whether that firm's capital allows it to do 'catch up' investments, 'regular' investments, or both. Subsequently, a consumer group is selected. If there is room for innovation in the selected

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[2] The minimum value of zero is necessary here because it would not make sense to state that a certain research project is expected to be –*x* steps ahead of the competition. This would happen in case the competition is expected to offer more value to consumers than the research project under consideration.

consumer group (i.e., the plant variety currently serving this group does not satisfy all consumer preferences), the script calculates the expected value to the selected consumer group of currently running research projects aimed at the selected consumer group, and stores this expected value in a vector. Then, the script stores the value to the selected consumer group of the plant variety that currently serves the relevant consumer group in the same vector. Subsequently, the expected value to the selected consumer group as well as the expected profits for the firm of various possible research projects that the firm can undertake are computed, and the research project with the highest expected profits is again stored in this vector, conditional on that the expected new plant variety offers more value to consumers than other currently running research projects or currently existing plant varieties. This condition is necessary, since it can be the case that the research project with the highest expected value offers less value to consumers than its competitors, due to which it would not sell at all.

This process is repeated for all consumer groups. Finally, the expected values for the firm of the research projects with the highest value to consumers are computed, one research project per consumer group. The firm chooses to invest in the research project with the highest expected value for the firm. After the decision is made, the investment costs are deducted from the firm's capital, and the selected research project is stored in the research projects matrix.

The process through which a firm decides on which research project to engage in deserves some elaboration. First, the company decides what trait, if at all, they should catch up with. This is determined by looking up the maximum values of various traits in the industry (i.e., the most developed version of different traits), calculating the value to consumers of catching up with a certain trait, and subsequently determining catching up with which trait would yield most satisfaction of consumer preferences. Note that catching up does not necessarily happen, for a company may be the leader in all traits. Even when the firm is not leader in a given trait, but it does completely satisfy the preferences of consumer group cg for that trait, catching up does not yield additional consumer satisfaction.

After deciding on the catching up part of the possible research project, the firm decides on which trait they should invest in using the regular (i.e., the non-catching up) part of the possible investment project. This is done by calculating the difference between consumer preference values and trait values of the plant of the selected firm (where the trait values of the plant take into account the catching up part of the investment process). The trait where this difference takes on the highest value is chosen as the trait in which the firm should invest. Note again that such regular investment is not necessary, for it may be the case that for the selected consumer group no innovation is possible (i.e., there are no differences between consumer preferences and the traits of the existing plant / the traits of the plant after catching up), or that only executing the catching up part of the possible research project yields a higher expected value than combining catching up- and regular research[3].

After every firm has been through the decision-making process, payoffs to firms of existing plant varieties are processed. This happens by determining the value to consumers of the plant variety that currently serves a given consumer group, subtracting the value to consumers of the best product of the competition (where 'best' is based on value to consumers), and multiplying the difference by the value of one innovation step. The payoffs are added to a firm's capital.

The patent model

The patent model deviates from the PBR model by not having the option to catch up with competitors' products. This means that whereas in the PBR model, firms can choose from research projects that only have a catching up part, only have a regular investment part, or have both, in the patent model only regular investments are available.

V. Results

As indicated in the outline of the model, the developed models are simulated for a period of 100 years, which is repeated ten times for every model. The results presented in this section are averages of those ten simulations, unless indicated otherwise. For a number of parameters, the values are varied in order to study the extent and direction of their effect on the output of the model. Those parameters are the interest rate, the value of one innovation step, and the costs of 'catching up' with the competition. This results in a number of scenarios that are run, which are described in table 2. The baseline results

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[3] This can happen, depending on the values various parameters have.

are those of the first scenario, in which the value of one innovation step is 50, the costs of catching up are 50% of regular investment costs, and the interest rate is equal to 5%.

Table 2: result scenarios

	PLANT BREEDERS' RIGHTS			PATENTS		
Scenario:	Value of one innovation step	Costs of 'catching up'†	Interest rate	Value of one innovation step	Costs of 'catching up'†	Interest rate
1	50	50%	5%	50	n/a	5%
2	50	50%	10%	50	n/a	10%
3	50	50%	1%	50	n/a	1%
4	40	50%	5%	40	n/a	5%
5	30	50%	5%	30	n/a	5%
6	50	75%	5%	n/a	n/a	n/a
7	50	25%	5%	n/a	n/a	n/a

† Displayed as percentage of 'regular' investment costs

Since this study focusses on the effect of the IPR regime on market structure and consumer satisfaction, the results report the capital that each firm accumulates, as well as the difference between consumer preferences of a certain consumer group and the plant variety currently serving that group. This difference in fact measures to what extent consumer preferences are not met, hence the lower this difference, the better consumers are served.

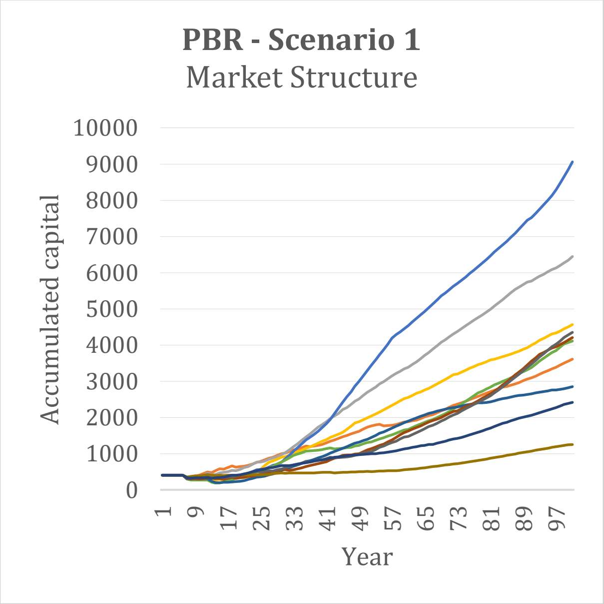


Figure 1a

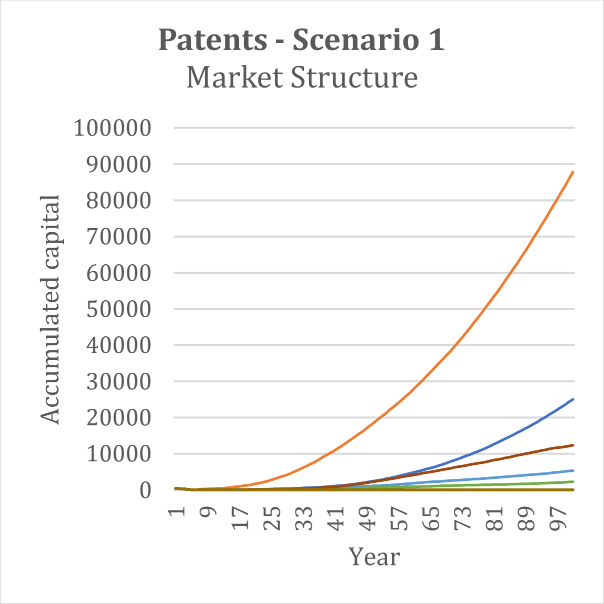


Figure 1b

The results of the first scenario regarding market structure are reported in figure 1a and 1b. Three main differences between the IPR regimes can be distinguished, namely the total amount of capital that the biggest firm accumulates, the relative size of the biggest firm, and the number of firms that can compete in the market. In the PBR model, the average accumulated capital of the biggest firm barely exceeds 9,000, whereas in the patent model this is nearly equal to 90,000, a difference of approximately factor 10. The largest firm in the PBR model accumulated roughly 40% more capital than the second-largest firm, whereas in the patent model the largest firm accumulated roughly 250% more capital than the second-largest firm. The number of firms that can compete in the market is equal to ten in the PBR model (which are all the firms in the model), whereas this number in the patent model is equal to five.

Figure 2a and 2b show the extent to which consumer preferences are *not* met by the plant variety currently serving a given consumer group. The main difference between the outcome of the PBR model and that of the patent model is that consumer preferences are better satisfied in the PBR model, given that on average, the difference between consumer preferences and what the plant variety currently serving them offers ranges between 1 and 8.5 in the patent model, whereas this difference ranges only between 0.5 and 4.5 in the PBR model. The shape of the lines in the graph may strike one as odd, but this is simply an artefact of the model since consumer preferences may change every six years, resembled by the jumps up, after which firms respond to them by introducing products that meet those preferences, resulting in jumps down.

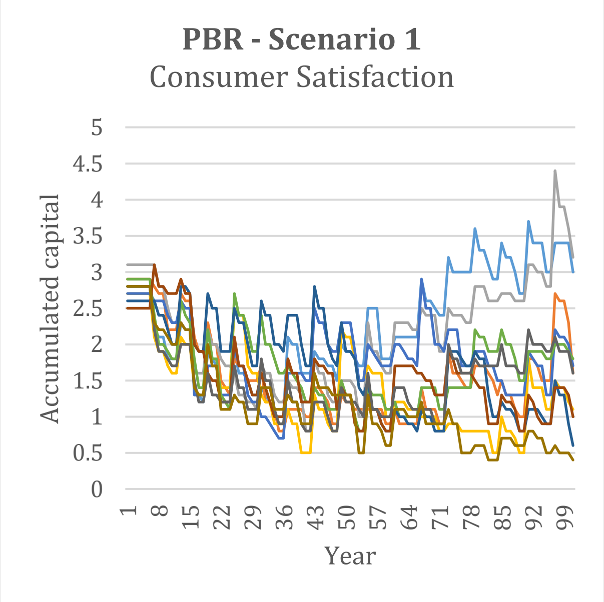


Figure 2a

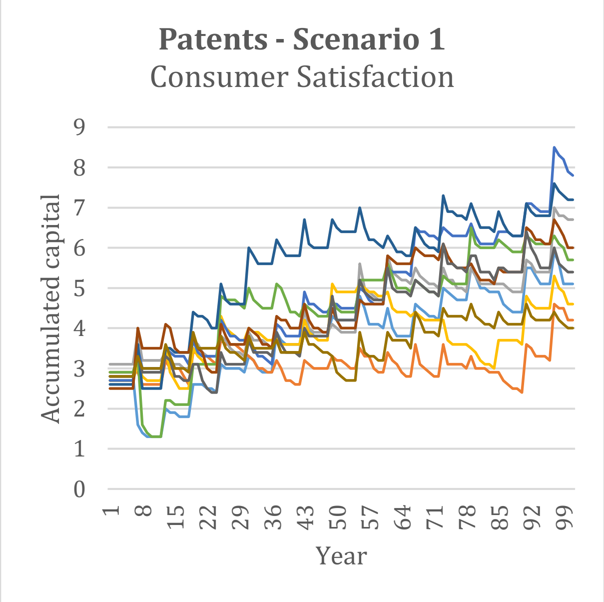
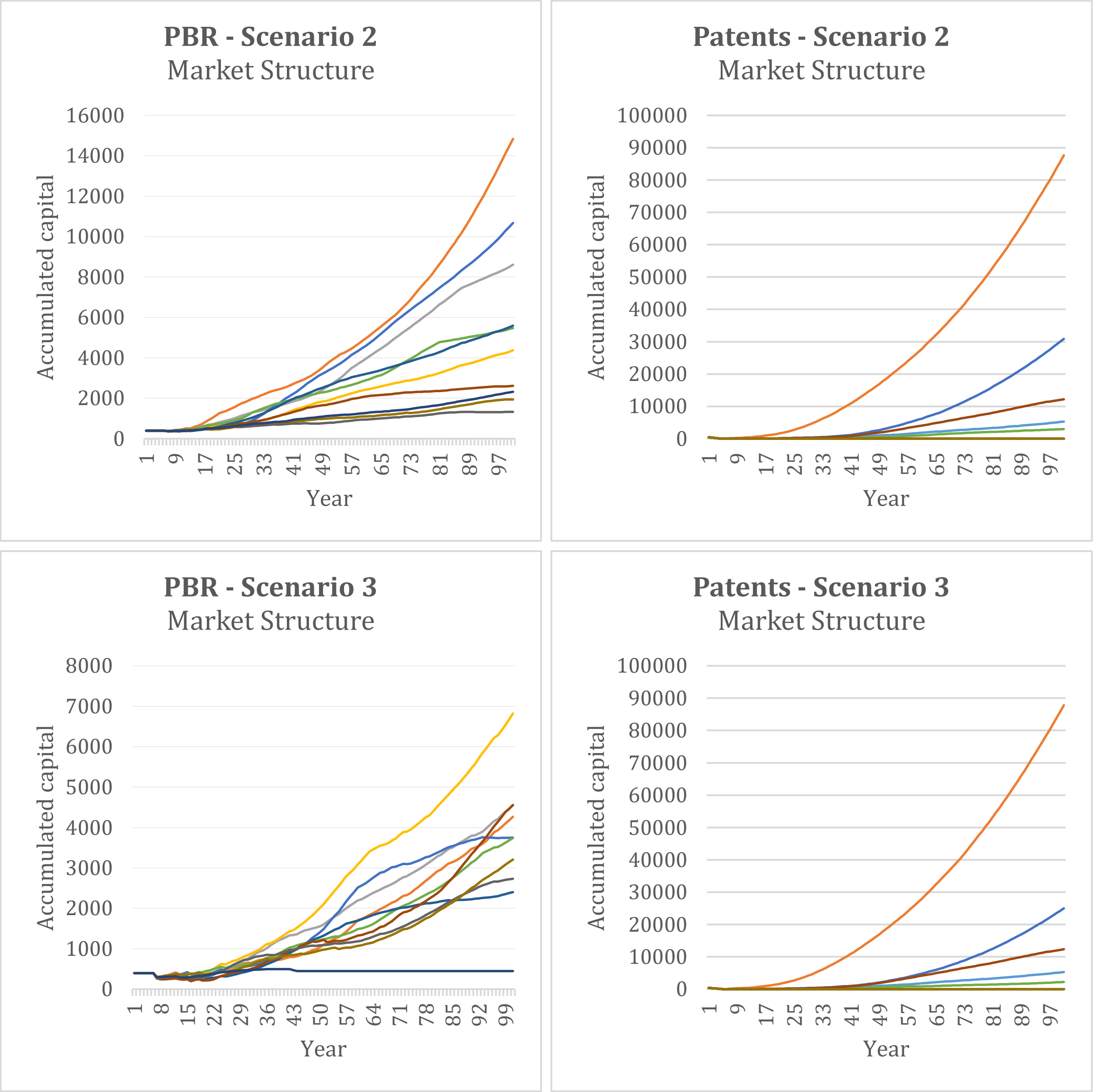


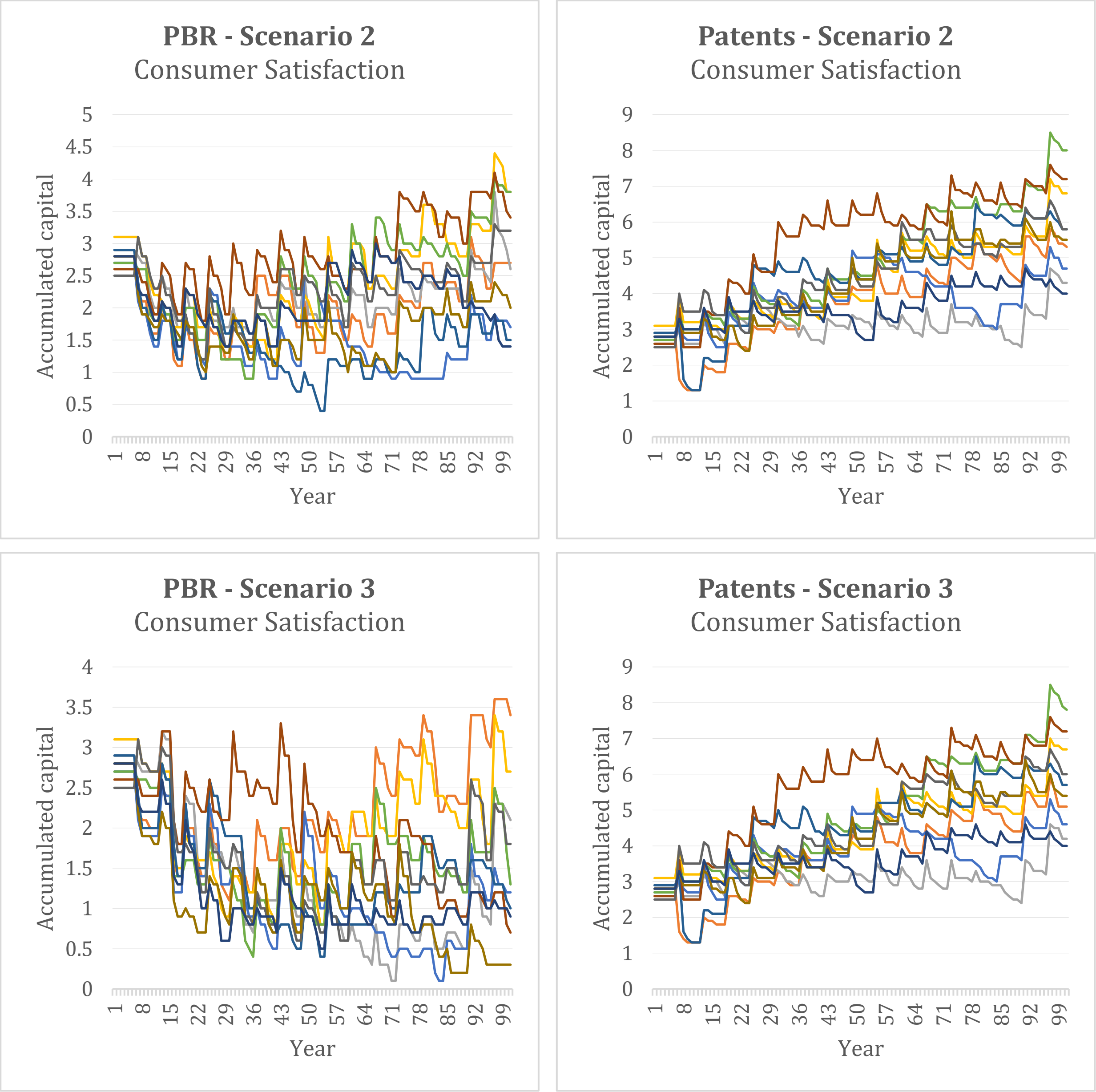
Figure 2b

The graphs in figure 3 depict the output of the model regarding market structure under high interest rates (figures 3a and 3b, 10% interest rate) and low interest rates (figures 3c and 3d, 1% interest rate). The overall conclusions do not differ from those in the main results: the patent model results in one very dominating firm with not so much competition, whereas in the PBR model there is one somewhat dominating firm, but competition is much more fierce. Even so, it is interesting to note that under high interest rates, in the PBR model (fig. 3a) the larger firms have a considerably larger payoff than in the baseline scenario, with the two largest firm having accumulated between 10,000 and 15,000 capital after 100 years, whereas in the baseline model this is only between 6,000 and 9,000. In the low interest scenario in the PBR model (fig. 3c), this is reversed, and the



From left to right, top to bottom: figure 3a, 3b, 3c, 3d. Scenario 2 is a high interest rate scenario (10%) whereas scenario 3 is a low interest scenario (1%). In the baseline scenario, the interest rate is 5%.

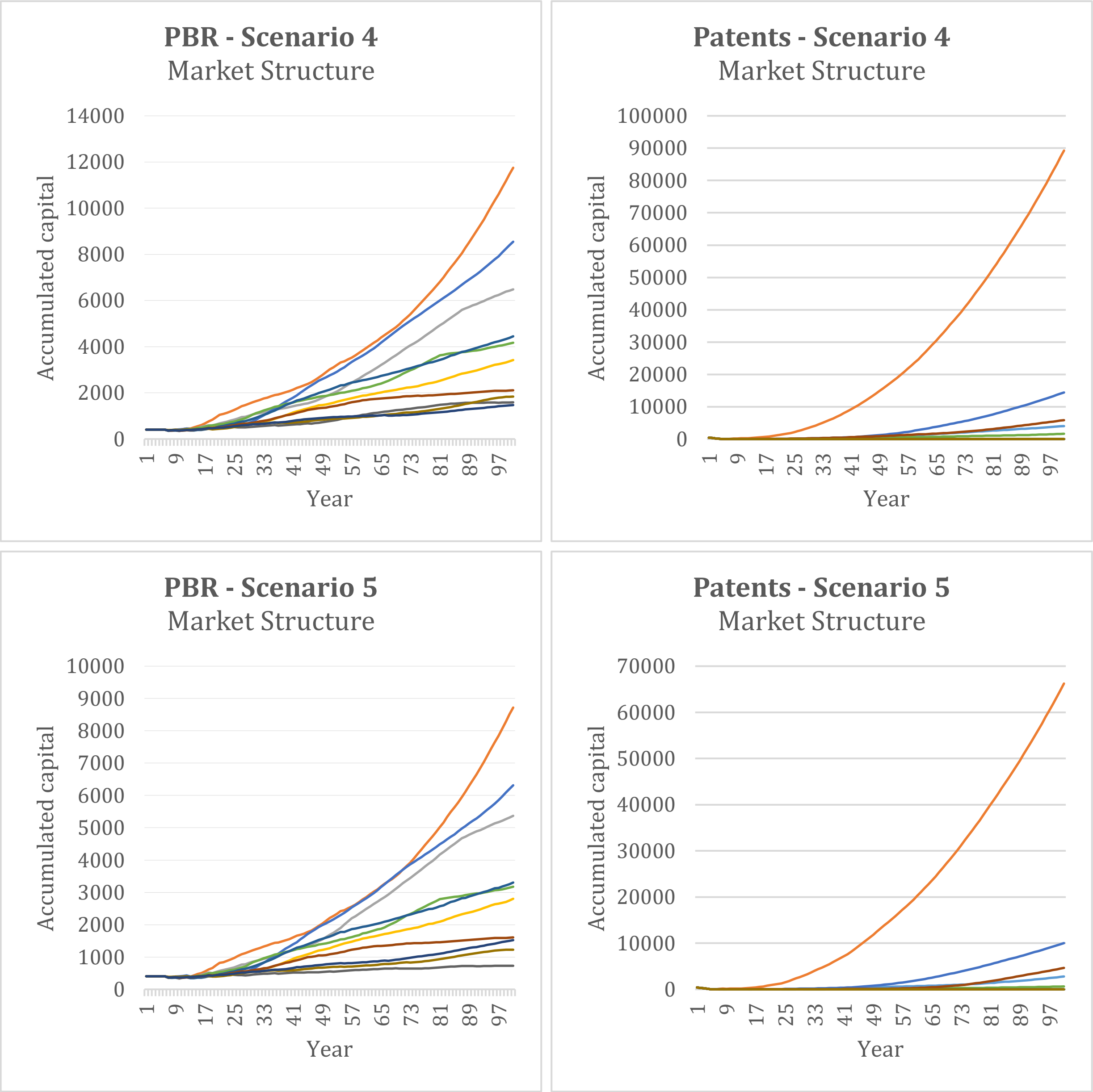
larger firms earn less than in the baseline scenario. The accumulated capital in the patent models with high or low interest rates do not deviate significantly from the baseline scenario.



From left to right, top to bottom: figure 4a, 4b, 4c, 4d. Scenario 2 is a high interest rate scenario (10%) whereas scenario 3 is a low interest scenario (1%). In the baseline scenario, the interest rate is 5%.

Similar to figure 3, the graphs in figure 4 depicts the outcome of the models regarding the satisfaction of consumer preferences under high interest rates (figure 4a, 4b, 10% interest rate) and low interest rates (figure 4c, 4d, 1% interest rate). Again, the overall conclusion is similar to those of the baseline scenario: in the PBR model, the overall industry is more able to serve consumer preferences than in the patent model. This is especially apparent in the low interest model.

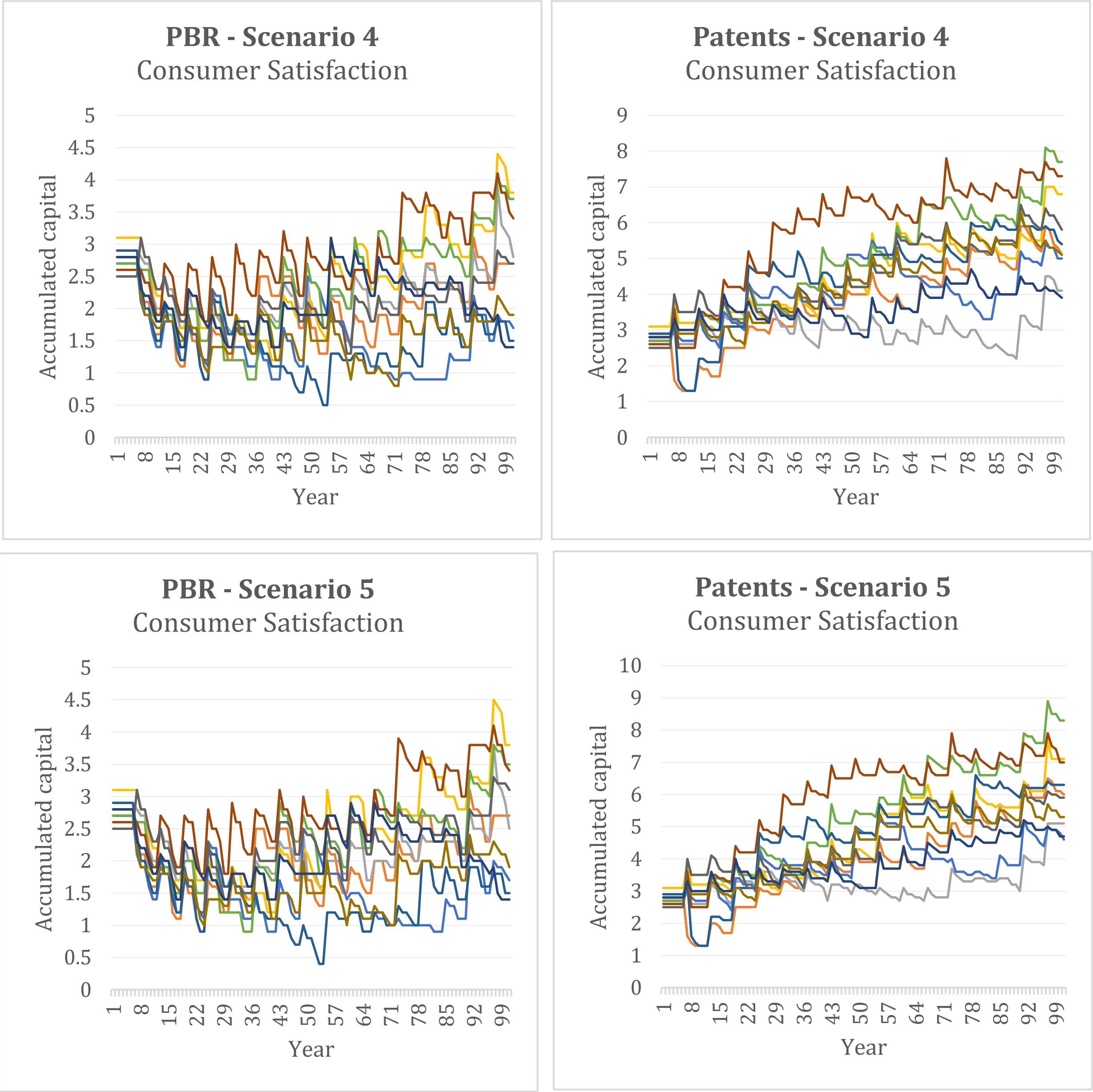
Decreasing the value of one innovation step to 40 (scenario 4) or 30 (scenario 5) does not change the conclusion of the baseline scenario regarding market structure. It may be interesting to note that decreasing the value of one innovation step in fact increases the payoffs of the largest firms in the PBR model (figure 5a). A possible explanation for this is that the lower value per innovation step makes it less attractive for competitors to invest in plants where the largest firm is leading. In the other figures, decreasing the value of one innovation step either keeps the highest payoffs equal or decreases them to some extent.



From left to right, top to bottom: figure 5a, 5b, 5c, 5d. In scenario 4, the value of one innovation step is equal to 40, whereas in scenario 5, this value is equal to 30. In the baseline scenario, this value is equal to 50.

Also for the satisfaction of consumer preferences, decreasing the value of one innovation step does not change the results much (see figure 6 below). The conclusions of the baseline scenario also hold in this scenario.

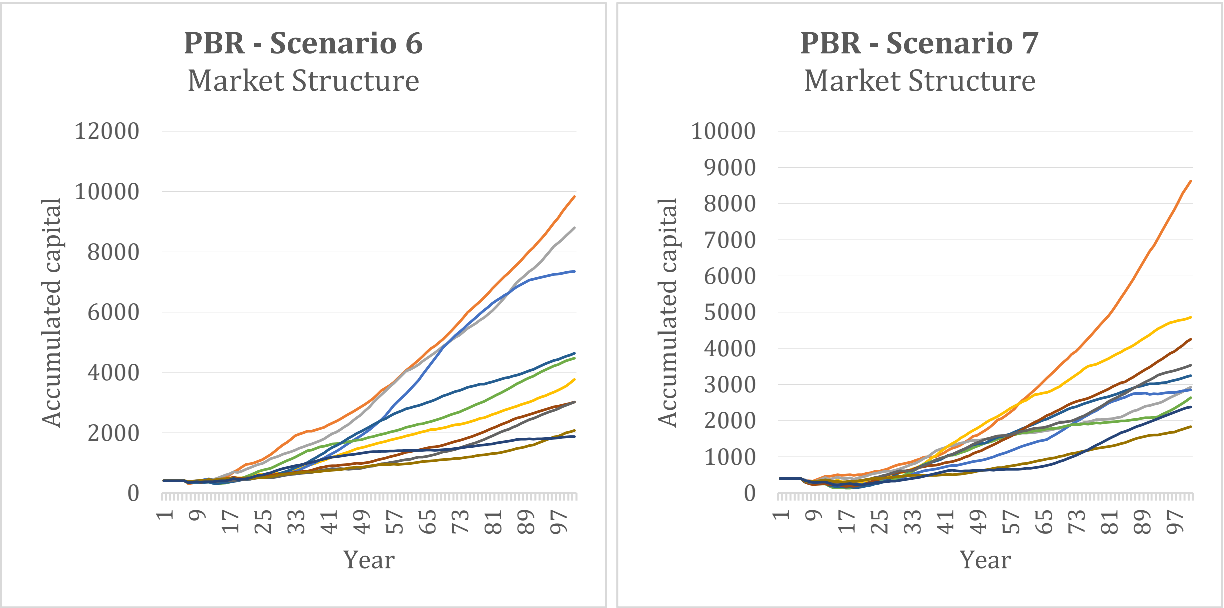
Decreasing the value of one innovation step to 20 does not yield any results, for the expected value of regular research projects, with which firms in the PBR model also have to start, is always negative.



From left to right, top to bottom: figure 6a, 6b, 6c, 6d. In scenario 4, the value of one innovation step is equal to 40, whereas in scenario 5, this value is equal to 30. In the baseline scenario, this value is equal to 50.

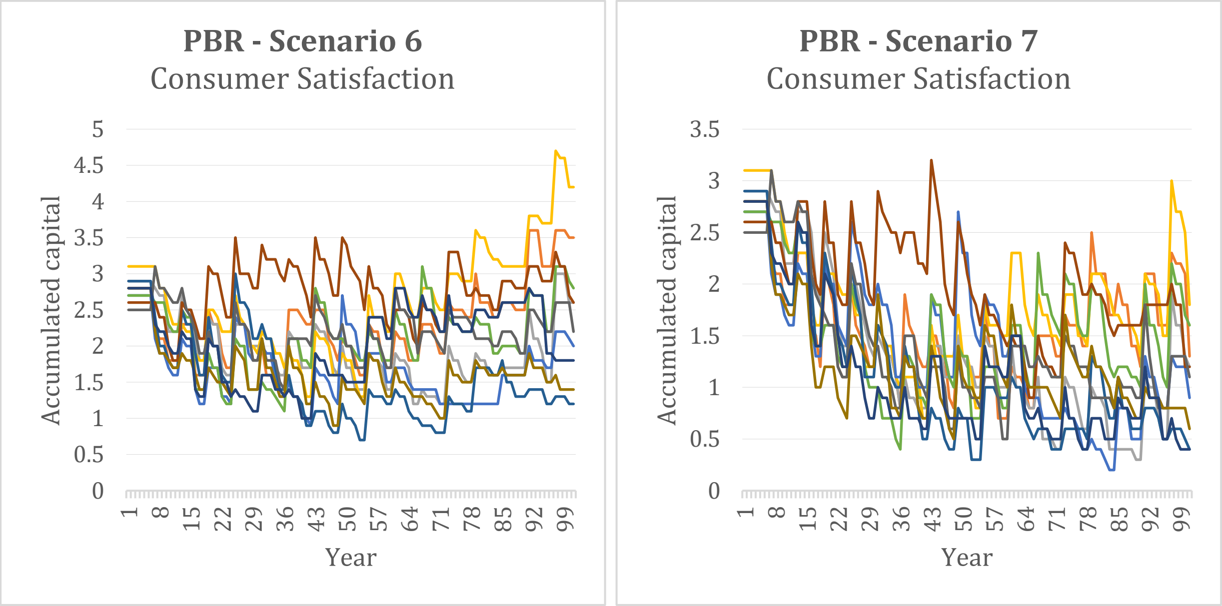
The results from changing the costs of a ‘catching up’ research project are displayed in figure 7 (for market structure) and figure 8 (for consumer satisfaction).

Results from the patent model are not displayed, since there does not exist such thing as 'catching up' investments under a patent regime. The market structures resulting from varying the 'catching up' costs do not differ much from the baseline scenario, although it may be interesting to note that lower 'catching up' costs seems to lead to one firm accumulating considerably more capital than the competition, while higher 'catching up' costs seems to have the opposite result. This may seem odd, since lower costs should incentivize firms to perform more R&D and hence accumulate more capital. However, due to the assumed type of competition, where firms can only charge prices equal to the marginal value they can offer compared to their competitors, firms performing more R&D does not necessarily result in more accumulated capital. Since every firm engages in more R&D, more and more developed plant varieties enter the market. This results in tougher competition, due to which prices that firms can charge are lower, which in turn results in less firms being able to accumulate considerably more capital than the other firms.



From left to right: figure 7a, figure 7b. In scenario 6, the costs of a 'catching up' research project is 75% of the costs of a regular research project. In scenario 7, this is 25%. In the baseline scenario, this is 50%.

The effect of varying the 'catching up' costs on the satisfaction of consumer preferences does not change much in case the costs are increased to 75% of the costs of a regular investment, however, if it is changed to 25% of the costs of a regular investment the industry is considerably more able to satisfy consumer preferences. This confirms the explanation given above of the differences in accumulated capital as a results of varying 'catching up' costs: the increased satisfaction of consumer preferences in the low-cost scenario indicates that more R&D is performed compared to the high-cost scenario, which results in tougher competition. Furthermore, whereas in other scenarios the extent to which consumer preferences are satisfied seems to decrease over time (after increasing at first), this decrease is absent in scenario 7 (figure 8b).



From left to right: figure 8a, figure 8b. In scenario 6, the costs of a 'catching up' research project is 75% of the costs of a regular research project. In scenario 7, this is 25%. In the baseline scenario, this is 50%.

VI. Discussion & Conclusion

This paper studied how different IPR regimes, namely Plant Breeders' Rights and patents, affect market structure and consumer satisfaction in the plant breeding industry. In order to do so, this paper employed a Monte Carlo simulation technique. This approach was preferred over the more common approach of developing a mathematical model and solving it analytically, since it allows for developing a more complex model and tracking the behaviour of the model over time.

The effect of the different IPR regimes on market structure was studied by looking at average accumulated capital over time. The simulation results show that under a patent approach, there is a tendency for one firm to strongly dominate the market, with a few smaller firms as competitors, whereas under the PBR approach, a few firms do dominate the market, but this domination is significantly less strong than under the patent approach. This suggests that the patent system facilitates monopolistic tendencies in the market, which are countered under the PBR approach by the breeders exemption. The effect of the different IPR regimes on consumer satisfaction was studied by looking at to what extent consumer preferences are satisfied. The simulation results show that under the PBR approach, consumer preferences are satisfied better than under the patent approach.

The findings of this paper differ from Moschini and Yerokhim's (2008) findings, specifically with respect to social welfare and consumer satisfaction. Moschini and Yerokhim (2008) find that in the case of relatively high R&D costs, a system without breeders' exemption is preferred, and vice versa in case of relatively low R&D costs. Simulating cases with relatively higher and lower costs by varying the value of innovation steps, this paper finds that in all cases, the PBR approach dominates the patent approach. The results in this paper are more or less in agreement with the findings of Lence et al. (2016), who find that a PBR approach dominates a patent approach if the type of research is straight-forward and applicable across many firms, improved varieties have a short expected commercial life span, and with research programmes that make incremental gains. Those conditions are met in this paper: research is straight-forward, is applicable across many firms and is incremental, for it simply consists of improving traits of plant varieties. The expected commercial life span is set on six years, which can be seen as a rather short expected commercial life span. The present paper is not able to confirm or disconfirm the scenario in Lence et al. (2016) where the patent system dominates, for in the present model there exists no path-breaking research, very specific research, or long expected commercial life spans.

The results have some implications for IPR policies. Given that the setup of the model in this paper resembles the actual plant breeding sector closely, the results clearly indicate the advantage of the PBR approach over the patent approach. However, given the findings of Lence et al. (2016) where patents dominate in some scenarios, and PBR dominates in others, and given that the nature of plant breeding, especially in the United States, and to a lesser extent in Europe, seems to change from more traditional breeding to increasingly high-tech and high-cost research (Lence et al., 2016), the conclusions and policy implications of this paper may not hold for every context. Hence, it is of utter importance for policy makers to thoroughly understand the environment in which the plant breeding sector operates before designing policy plans.

The present study has a number of limitations. As already indicated, the model does not allow for conclusions regarding contexts in which research is path-breaking, is very specific, or has long expected commercial life spans. Also, licensing is not included in the model, due to which the patent system is represented somewhat less accurately. The motivation for leaving licensing out is due to the asymmetric information issues associated with licensing (Gallini and Wright, 1990; Bessen, 2004), which would not be possible to incorporate in this model since the opportunities for innovation are known to every firm. Furthermore, due to the specific setup of the model, the conclusions are specific for the plant breeding sector, and cannot readily be extrapolated to other sectors, unless those other sectors closely resemble the structure of the plant breeding sector.

There are some interesting possibilities for further research. First, a similar model could be developed that is able to distinguish between the incremental, more general type of research conducted in the present model and the path-breaking, more specific type of research that Lence et al. (2016) employ. Furthermore, the model could be adapted in such a way that it includes an asymmetric information structure, which could be used to incorporate the issue of licensing. Also, one could attempt to generalize the model, so that the conclusions are not only valid for the plant breeding sector but also for various other sectors in which R&D plays an important role.

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