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Three essays on the economics of innovation

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Three essays on the economics of innovation

by

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For the Major Program

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CHAPTER 1. GENERAL INTRODUCTION

1. Introduction

Economists have long understood that innovations are at the root of modern economic growth, and many studies have been devoted to various aspects of the subject. Nevertheless, the rapid scientific and technological breakthroughs observed almost in all industries (biotechnological innovations in agriculture, for example) and the legal and institutional changes favoring stronger intellectual property rights in the last decades, provide new opportunities and challenges for research in this area. This thesis comprises three essays which identify and address specific problems at critical stages of the innovation process.

Innovations are typically the result of some knowledge production and research processes, the output of which are public goods and are subject to market failure problems (Arrow, 1962). Regardless of how costly it is to come up with an invention, its reproduction often can be very easy and at low cost. As society benefit due to the non-exclusive nature of knowledge, inventors may not recoup the investment in their discovery activities. Secondly, uncertainty is part of the research process. These features justify the existence of intellectual property rights and government involvement in research activities in order to stimulate inventions.

Innovations can be protected by intellectual property rights (IPRs) in market economies, which are typically patents, trade secrets, copyrights, and trademarks. The strongest form of protection is patents, which offer monopoly rights for a limited time in return for the full disclosure of innovations. Although other forms of IPRs are used in areas not covered by patents, trade secrets apply to the patentable innovations as well. By opting out for trade secrets, inventors forego the disclosure requirement necessary under patents but are provided limited protection. Alternative mechanisms to induce innovations, such as prizes, rewards, and procurement contracts, may not be efficient in practice due to the informational asymmetry on the side of government. Therefore, patents provide a second best solution to information problems. As patents aim to promote the flow of innovations, they can create their own problems. The monopoly positions they provide limit the social optimal use of innovations. Moreover the competition for the rent position that patents promise can create inefficiencies.[1] In a race to patent a given invention, which is typically modeled as a winner-takes-all contest, in equilibrium firms may end up providing an inefficient amount of R&D (invest too much) but may also provide the wrong "type" of R&D. Specifically, projects that are chosen may be excessively risky and excessively correlated compared to the social optimum. The first essay (Chapter 2) revisits the problem of correlation choices in Dasgupta and Maskin (1987) by taking into account the fact that firms have the option of trade secrecy in addition to patents in protecting their inventions. We find that the availability of multiple IPR protection instruments can move the paths chosen by firms engaged in a winner-takes-all race towards the social optimum.

In stimulating the inventions, government agencies can be directly involved by carrying out research in public institutions or funding research projects in universities, especially those in basic science, which are more likely to suffer from market failure problem and uncertainty, and therefore less likely to be undertaken by private firms. In fact, this is what happened in the United States in the last century and the output of publicly funded research was put in the public domain and established an "open science" environment, which is in line with the cultural norms of universities. Such a system received important credit in scientific breakthroughs.

Nevertheless, based on an argument which presumes that without exclusive licenses private firms do not have enough incentives to develop "embryonic" university inventions, the Bayh-Dole Act of 1980 made it possible for universities and other non-profit organizations to retain title to patents derived from federally funded research, and therefore to license the inventions to private firms, possibly on an exclusive basis. Since the Act, there has been a dramatic surge in patenting and

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[1] See Langinier and Moschini (2002) for a recent review of the literature.

licensing activities by U.S. universities. This growth in university patenting and licensing activities has resulted in a considerable debate in the literature, which has revolved around how these activities have affected the traditional role of universities (advancement of science and dissemination of knowledge), how they impacted the other channels (publications, conferences and others) through which the universities transfer knowledge, and whether the Bayh-Dole Act was in fact necessary to promote technology transfer.

The third essay (Chapter 4) aims to contribute to this discussion by studying the basic, yet somewhat unexplored, question of whether in fact universities in expectation, are earning economic rent (profits) from licensing activities. We mostly utilize the data from AUTM (Association of the University Technology Managers) surveys on various licensing activities of U.S. universities and some university characteristics, and other sources. The data include 148 observations from U.S. universities and cover the five years time period 1998 to 2002. We estimate a structural econometric model and identify the key determinant of license rent generation as the quality of faculty (which is measured by the citations received in technology departments), together with the size of the university in terms of total research expenditures.

After innovations have taken place, and possibly receive some form of IPR protection, the diffusion and adoption processes begin. Once introduced in the market, inventions can create distributional economic effects across economic agents as they may replace or provide alternatives to existing products. The second essay (Chapter 3) studies an application in this context: Genetically Modified (GM) crops, which are based on IPR-protected innovations that consist of the insertion of foreign genetic material into traditional crops to obtain desired attributes, such as herbicide and pest resistance. Although GM crops have been quickly adopted in certain parts of the world, they have met with resistance from consumers in the European Union (EU) market. This has resulted in a complex (and ongoing) EU regulation, which envisions the co-existence of GM food with conventional and quality-enhanced products. As the regulation mandates the labeling and traceability of GM content at all stages of production, and allows only a stringent adventitious presence of GM content in other products, it implies significant economic costs. Based on a partial equilibrium modeling of the EU agricultural food sector, we analyze the economic implications of the introduction of GM food in the EU market. We develop and calibrate a model to replicate the EU agricultural data in 2000. We find in the baseline solution of our model that the introduction of GM food is reducing overall welfare (both consumers and producers become worse off), but the producers of quality-enhanced products may become better off. We also solve the model for alternative scenarios and do sensitivity analysis to key parameters of the model.

2. Thesis Organization:

The three essays briefly described in the preceding section are self-contained with their own Introduction, Conclusion and References sections. Following these essays is the General Conclusion section.

3. References (for General Introduction)

Arrow, K.J. 1962. "Economic Welfare and the Allocation of Resources for Inventions." In *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Edited by R.R. Nelson. Princeton, NJ: Princeton University Press.

Dasgupta, P., and E. Maskin. 1987. "The Simple Economics of Research Portfolios." *Economic Journal* 97: 581-95.

Langinier, C., and G. Moschini. 2002. "The Economics of Patents: An Overview." In *Intellectual Property Rights in Animal Breeding and Genetics*. Edited by M. F. Rothschild and S. Newman. New York, NY, CABI Publishing.

CHAPTER 2. PATENTS, TRADE SECRETS AND THE CORRELATION AMONG R&D PROJECTS[1]

Abstract

The choice of a research path in attacking scientific and technological problems is a significant component of firms' R&D strategy. One of the findings of the patent races literature is that, in a competitive market setting, firms' noncooperative choices of research projects display an excessive degree of correlation, as compared to the socially optimal level. The paper revisits this question in a context where firms have access to trade secrets, in addition to patents, to assert intellectual property rights (IPRs) over their discoveries. We find that the availability of multiple IPR protection instruments can move the paths chosen by firms engaged in a R&D race towards the social optimum.

1. Introduction

By endowing inventors with exclusive property rights over their discoveries, patents can be a powerful incentive for undertaking new research and development (R&D) projects in a market economy, thereby promoting the flow of innovation that is at the root of modern economic growth. Ancillary benefits that are often cited include the patent system's role in disseminating new knowledge and in helping technology transfer and commercialization of new inventions. But patents are a quintessential second-best solution to very real market failures that affect the provision of

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[1] This is a joint paper with GianCarlo Moschini.

innovations in a competitive setting. Whereas they solve some incentive problems, the monopoly positions engineered by patent rights can create other inefficiencies (see Scotchmer (2004) or Langinier and Moschini (2002) for an overview). The economic issues raised by patent races are a case in point. The competition for the economic rents secured by a patent provides incentive for parallel research (Dasgupta, 1990). Given that R&D projects have uncertain outcomes, some parallel research may be desirable from the social point of view because it increases the probability of success. But because the reward to firms engaged in a patent race is in the form of winner takes all, too much parallel research is also possible in a competitive setting, an example of the rent dissipation postulate (Tirole, 1988).

In addition to providing a possibly inefficient *amount* of R&D investment, parallel research also may fail to provide the correct *type* of R&D efforts. Specifically, competitors in a patent race may choose strategies that are too risky from society's viewpoint (Klette and de Meza, 1986). More subtly, R&D competitors may choose projects that are excessively correlated relative to what is socially desirable. Expanding on earlier work by Bhattacharya and Mookherjee (1986), Dasgupta and Maskin (1987) showed that projects selected by firms engaged in a patent race are in fact excessively correlated. Cabral (1994) showed that the excess risk result is sensitive to the specification of the winner-takes-all assumption, and a model allowing for post-R&D oligopoly market sharing may actually induce the opposite bias (too little risk-taking in R&D). However, excess correlation of R&D still obtains in his model. Cabral (2002) studied the strategic choice of covariance in a dynamic R&D model and showed that, in equilibrium, laggards may want to diversify from leaders, thereby choosing less promising paths.

In this paper we revisit the issue of excessive correlation in a parallel research setting by investigating the impact of a more realistic institutional setting. Specifically, it is known that firms rely on multiple modes of protection for their discoveries. Trade secrets, lead time, and manufacturing capabilities not only complement patents in helping firms appropriate returns from

R&D activities but are often considered more important (Cohen, Nelson and Walsh, 2000). Indeed, the reported importance of trade secrecy increased dramatically compared to earlier industry surveys (Arundel, 2001). Trade secrets are particularly attractive to inventors when a discovery is difficult and costly to reverse engineer and/or discover independently (Daizadeh et al., 2002). In agricultural innovations, for example, this has been the case for proprietary germplasm. Pioneer Hi-Bred International successfully used trade secrets to protect its germplasm in at least two high-profile cases (against Holden Foundation Seeds, Inc. in 1991, for a judgment worth $46.7 million, and against Cargill, Inc. in 2000, for a settlement worth $100 million). More generally, Lerner (1995) finds that trade secret disputes captured 43 % of intellectual property litigations.

The impact of alternative modes of intellectual property protection has been the object of a number of studies. In line with the strategic patenting hypothesis discussed in the empirical literature, Horstmann, MacDonald and Slivinski (1985) consider the relative advantage of the explicit choice not to patent. In a signaling model, Scotchmer and Green (1990) consider not patenting as alternative to patenting intermediate discoveries in a multi stage innovation race. Anton and Yao (2004) study the choice between patenting and trade secrets to process innovation in a Cournot competition setting. Denicolo and Franzoni (2004) explicitly model multiple modes of protection available to innovators in studying the ability of patents to exclude prior users. Note that these studies have focused on the choice of research intensity. However, the choice of research paths in attacking scientific and technological problems is a significant component of firms' R&D strategy (Cabral, 2003).

Does the availability of alternative modes of protection impact the research paths chosen by R&D competitors? That is essentially the question that we propose to analyze in this paper, and we do so by developing a simple model that combines features of Dasgupta and Maskin (1987) and Denicolo and Franzoni (2004) analyses. In particular, we model the strategic interaction between firms both at the stage of project selection and at the stage of intellectual property (IP) choice.[2] By linking research and IP game stages, we are able to analyze how the availability of intellectual property rights (IPR) protection instruments affects some relevant research choices in a parallel R&D contest. We find that the availability of additional modes of protection (trade secrets in our model) may in fact lead R&D competitors to choose less correlated projects. The root of our finding is that the presence of an additional IPR instrument introduces an asymmetry on how firms are rewarded in the event of success. Specifically, when there is a single winner in the R&D contest, the availability of trade secrets (in addition to patents) means that the firm has the option of selecting a possibly more profitable IPR protection. But when both firms are successful, the strategic game between firms makes the additional IPR protection instruments less useful. Thus, the presence of trade secrets in addition to patents provides an additional incentive to be the sole winner, thereby driving firms' R&D choices closer to the social optimum for a range of parameter values. We conclude that modeling parallel research with just one winner-takes-all instrument (i.e., patents) may exaggerate the concerns about the insufficient diversification of privately chosen research portfolios. Our model is also useful in recovering a role for patent length as a policy tool in this context, shedding perhaps a novel light on the interaction among alternative IPR protection modes.

2. The Modeling Framework

The starting point of our model is the two-point distribution approach introduced in Dasgupta and Maskin (1987). The R&D contest is represented as a one-shot game in which two firms (firm 1

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[2] The competition in the research stage is often suppressed in the literature studying strategic patenting, where it is usually assumed that one of the firms is the winner of the research contest, and a leader-follower situation arises at the patenting stage (e.g., Horstmann, MacDonald and Slivinski 1985; Denicolo and Franzoni 2004; and Bessen 2004). On the other hand, studies focusing on the research stage competition typically do not model the strategic interaction in the choices concerning intellectual property protection (e.g., Dasgupta and Maskin 1987).

and firm 2) simultaneously pursue a research project, the outcome of which is either "success" (denoted with S) or "failure" (denoted with F). Let $X_i \in \{S,F\}$ denote the random outcome for the i^{th} firm ($i=1,2$), such that four events (X_1,X_2) are possible: (S,S), (S,F), (F,S), and (F,F). Let p_i and ρ denote the i^{th} firm's unconditional probability of success, and the coefficient of correlation of the dichotomous variables X_i (e.g., Hays and Winkler, 1970, pp. 206-208), respectively. The probabilities of the four possible events are as follows:

$$prob\left(S,S\right) = p_1 p_2 + Cov(X_1,X_2), \tag{1.a}$$

$$prob\left(S,F\right) = p_1(1-p_2) - Cov(X_1,X_2), \tag{1.b}$$

$$prob\left(F,S\right) = (1-p_1)p_2 - Cov(X_1,X_2), \tag{1.c}$$

$$prob\left(F,F\right) = (1-p_1)(1-p_2) + Cov(X_1,X_2), \tag{1.d}$$

where $Cov(X_1,X_2) = \rho\sqrt{p_1(1-p_1)p_2(1-p_2)}$ is the covariance term.

As in Dasgupta and Maskin (1987), in this setting the presumption is that a firm can unilaterally diversify from its rival (thereby reducing the correlation of outcomes) at the expense of decreasing its own unconditional probability of success. Thus, we assume that each firm can choose a level of diversification effort $a_i \in [0,1]$ that affects both the unconditional probability of success p_i as well as the correlation/covariance of outcomes, where $a_i = 0$ represents no diversification effort of firm i and $a_i = 1$ represents firm's i maximum diversification.[3] Specifically, we write $p(a_i) = p_i$, $i=1,2$, and $C(a_1,a_2) = Cov(X_1,X_2)$.[4] In the analysis that follows we rely on the following:

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[3] Note that our specification differs slightly from that adopted by Dasgupta and Maskin (1987). In particular, they consider the project space to be $\left[1/2\,,1\right]$ for firm 1 and $\left[0\,,1/2\right]$ for firm 2. Also, their parameterization of the covariance structure differs from the canonical form given above.

[4] Because the success probability function $p(\cdot)$ is the same for both firms, the covariance function is

Assumption 1. (i) The unconditional probability function $p(a_i)$ is strictly decreasing and strictly concave in its domain, with maximum at $a_i = 0$ and minimum at $a_i = 1$. (ii) The covariance function $C(a_1, a_2)$ is strictly decreasing in a_i ($i = 1,2$). (iii) The probability of event (F, F), that is $[1 - p(a_1)][1 - p(a_2)] + C(a_1, a_2)$, is strictly convex in a_i ($i = 1,2$) .

As in Dasgupta and Maskin (1987), it may also be desirable to restrict attention to the case of nonnegative covariance, such that maximum diversification choices entail $C(1,1) = 0$.

2.1. Social Optimum

In this setting, the question of interest concerns what the noncooperative choices of the two firms are, and how that compares with the desirable choices from society's viewpoint. To address that in the simplest case, following Dasgupta and Maskin (1987) we assume that the payoff to society of at least one project being successful is $B > 0$, and we abstract from cost considerations. Thus, expected social welfare can be written as $B \cdot [1 - prob(F,F)]$ so that the social planner's problem is:

$$\max_{a_1, a_2} \; B \cdot [1 - prob(F,F)] \tag{2}$$

Therefore, the social planner maximizes the total probability of success. The objective function in equation (2) is strictly concave by Assumption 1, and thus we have a unique solution to the welfare maximization problem.

Given our formulation, the solution to the problem in (2) is symmetric and it is labeled (a^*, a^*). Note that, because $prob(F,F) = 1 - prob(S,F) - p(a_2) = 1 - prob(F,S) - p(a_1)$, from equations (1) the optimality conditions for an interior solution are equivalent to

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symmetric in project choices, that is $C(a_1, a_2) = C(a_2, a_1)$, $\forall \left(a_1, a_2\right) \in [0,1] \times [0,1]$. See Appendix A.1 for more details and implications of Assumption 1.

$$\frac{\partial prob(S,F)}{\partial a_1}=\frac{\partial p(a_1)}{\partial a_1}[1-p(a_2)]-\frac{\partial C(a_1,a_2)}{\partial a_1}=0 \ , \tag{3.a}$$

$$\frac{\partial prob(F,S)}{\partial a_2}=\frac{\partial p(a_2)}{\partial a_2}[1-p(a_1)]-\frac{\partial C(a_1,a_2)}{\partial a_2}=0 \ . \tag{3.b}$$

That is, the social planner effectively maximizes the probabilities that each firm is the single winner. In doing this, it weighs the loss of the unconditional probability of success against the (optimal) diversification gain through the covariance term.

2.2. Noncooperative solution

By contrast, in a competitive R&D setting, firms simultaneously choose research projects in a non-cooperative fashion. Let U_{SS} denote the expected payoff to each firm when both firms are successful, let U_S denote the payoff to a single successful firm, and let U_F be the payoff to the firm that fails (whether alone or jointly with the other firm). It is assumed that $U_S \geq 2U_{SS} > U_F = 0$.[5] Then, the firms' optimization problems (conditional on the other firm choice) are:

$$\max_{a_1} \ V_1(a_1,a_2)\equiv U_{SS}\cdot prob(S,S)+U_S\cdot prob(S,F), \tag{4.1}$$

$$\max_{a_2} \ V_2(a_1,a_2)\equiv U_{SS}\cdot prob(S,S)+U_S\cdot prob(F,S), \tag{4.2}$$

with first order conditions (FOCs) for an interior solution:

$$U_{SS}\frac{\partial prob(S,S)}{\partial a_1}+U_S\frac{\partial prob(S,F)}{\partial a_1}=0, \tag{5.1}$$

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[5] The condition $U_{SS} > 0$ presumes that competition between successful innovators does not dissipate the rent created by the innovation, an outcome that is likely under a variety of market conditions (Cabral, 1994). The condition $U_S \geq 2U_{SS}$ simply means that a monopoly is at least as profitable as a duopoly.

$$U_{SS}\frac{\partial prob(S,S)}{\partial a_2}+U_S\frac{\partial prob(F,S)}{\partial a_2}=0, \qquad (5.2)$$

which yield the firms' best response functions. Note that, because by Assumption (1) $prob(F,F)$ is convex in (a_1,a_2) and $p(a_i)$ is concave, then $prob(F,S)$ and $prob(S,F)$ are concave in (a_1,a_2) (see Appendix A.1.2). Furthermore, in view of (1), the firms' objective functions can alternatively be written as $V_1(a_1,a_2)=U_{SS}\cdot p(a_1)+(U_S-U_{SS})\cdot prob(S,F)$ and $V_2(a_1,a_2)=U_{SS}\cdot p(a_2)+(U_S-U_{SS})\cdot prob(F,S)$, and therefore they are concave in the decision variables. Hence, the FOCs in (5) are both necessary and sufficient for a maximum. The (symmetric) competitive market portfolio—the Nash equilibrium, denoted with (a^c,a^c)—satisfies the best response functions of both firms, i.e., it solves equations (5). We shall further restrict our analysis as follows.

Assumption 2. The problems in (2) and (4) admit solutions that lie in the interior of $[0,1]\times[0,1]$.[6]

The following result (Proposition 3 in Dasgupta and Maskin, 1987) then follows.

Proposition 1. *The noncooperative solution consists of projects that are too highly correlated, relative to the social optimum. That is,* $a^c < a^*$.

Proof. By assumption $U_{SS}>0$ and, given Assumption 1, $\partial prob(S,S)/\partial a_i<0$, $i=1,2$. Hence, if equations (3) hold, equations (5) cannot hold. Specifically, the FOCs for the social optimum, when evaluated at the noncooperative equilibrium solution, are positive. Because the second order

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[6] See Appendix A.2 on sufficient conditions for interior solutions.

sufficient conditions (SOSCs) for the planner's problem hold globally, the result of Proposition 1 follows.■

The intuition for this result is as follows. Whereas society does not care about the identity of the winner (i.e., society is indifferent between the outcomes (S,S), (S,F) and (F,S)), the firms of course do care. If, starting from the market equilibrium, a firm were to move away from the rival, towards the social optimum, it would create a positive externality for the opponent because it increases the probability that the opponent is successful when the firm in question is not. Although that is desirable for society because it increases the total probability of success, this effect is not taken into account in the firms' problem.

2.3. Comparative Statics

To extend the analysis of Dasgupta and Maskin (1987) with the aim of considering multiple modes of protection, we first note that the competitive (Nash equilibrium) solution depends on the relative magnitude of the payoffs U_{SS} and U_S. More specifically, the following preliminary result will be useful in what follows.

Lemma 1. *The symmetric Nash equilibrium of the noncooperative (interior) solution,* (a^c, a^c) *is such that.* a^c *is increasing in* U_S *(the payoff to a single successful firm) and it is decreasing in* U_{SS} *(the payoff when both firms are successful). Furthermore, if* $R \equiv U_{SS}/U_S$*, then* a^c *is decreasing in* R.

Proof. Let $\phi_i(a_1, a_2; U_S, U_{SS}) = 0$ denote the FOC in equations (5) ($i = 1,2$), such that the symmetric Nash equilibrium is the solution to $\phi_i(a^c, a^c; U_S, U_{SS}) = 0$. From standard comparative statics one can then establish that $sign\left(\partial a^c / \partial U_S\right) = sign\left(\partial \phi_i / \partial U_S\right)$ and $sign\left(\partial a^c / \partial U_{SS}\right) = sign\left(\partial \phi_i / \partial U_{SS}\right)$, as shown in the Appendix A.3.2. Furthermore, $\partial\phi_i/\partial U_{SS} = \partial prob(S,S)/\partial a_i|_{(a_1=a^c,a_2=a^c)} < 0$ and $\partial\phi_i/\partial U_S = \partial prob(S,F)/\partial a_i|_{(a_1=a^c,a_2=a^c)} > 0$. The first inequality follows directly from Assumption 1, and the second inequality follows from the fact that equation (5) holds. Similarly, $sign\left(\partial a^c/\partial R\right) = sign\left(\partial\phi_i/\partial R\right)$ and $\partial\phi_i/\partial R = \partial prob(S,S)/\partial a_i|_{(a_1=a^c,a_2=a^c)} < 0$. ■

The important implication here is that anything that increases the payoffs in the event of a single successful firm without changing the payoff in the event of both firms succeeding will tend to decrease the correlation of the firms' equilibrium choices. Similarly, decreasing the payoff when both firms succeed, while keeping the payoffs in other events constant, decreases the correlation of choices as well. This will be the basis for proving our main conclusion—that having different modes of IPR protection may lead to a more desirable outcome vis-à-vis the differentiation of firms' research projects.

3. The Model with Patents and Trade Secrets

To add an explicit consideration of alternative modes of protection, we continue to assume that research outcomes are common knowledge. The game tree for this case is depicted in Figure 1. Note that this extends the one-shot game discussed earlier by the addition of an intellectual property (IP) subgame. What were exogenous payoffs in Dasgupta and Maskin (1987) are made a function of IP choices along the lines of Denicolo and Franzoni (2004). Specifically, the winner of the research stage chooses between a patent and trade secret protection. The patent provides $T < \infty$ periods of absolute monopoly. If we were to interpret the social payoff B as the present value of a perpetual flow of benefits, then $B = \int_0^\infty be^{-rt}dt = \frac{b}{r}$, where b is the per-period benefit and r is the discount rate. We assume, for simplicity, that the patentee can capture the entire social surplus while the patent is valid, a patent lasting T periods provides a return of $\int_0^T be^{-rt}dt$. The reward from the patent protection can therefore be written as $\delta(T)B$, where

$$\delta(T) \equiv \left(1 - e^{-rT}\right) \tag{6}$$

denotes the fraction of total social surplus captured by the patentee.[7] We write $\delta(T)$ to emphasize that the reward offered by patents depends on a policy variable, the patent length T.

The protection offered by trade secrets, rooted in civil law, can provide an alternative way to secure a temporary monopoly. Unlike the case of patents, the monopoly is of random duration and ends whenever other firms independently invent or reverse engineer the invention, i.e., when the secret leaks out (Friedman, Landes and Posner 1991). Assuming an exponential distribution for the duration of the trade secret, the payoff in this case can be written as $\int_0^\infty be^{-(z+r)t}dt$, where the hazard rate z indexes the difficulty of concealing the invention (that is, e^{-zt} is the probability that the secret will not leak out by time t). Thus, the reward from trade secret protection can be written as $\gamma(z)B$, where

$$\gamma(z) \equiv \frac{r}{r+z} \tag{7}$$

represents the fraction of total social surplus that can be captured under trade secrecy protection. We write $\gamma(z)$ to emphasize that the strength of protection offered by trade secrets depends on the hazard rate $z \geq 0$. Furthermore, the value of trade secrets as an IPR protection instrument depends on the provisions established by law (mostly state law in the United States). Thus, in this setting the parameter z also can be considered a policy instrument.[8]

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[7] We assume that the social and private discount rates are identical, but this condition could easily be relaxed.

[8] As in Denicolo and Franzoni (2004), the parameter r could also account for the arrival rate of an alternative discovery that supersedes the technology. Under this interpretation, one may expect r to be higher under the patent choice than under secrecy, because the information disclosure required by patents may be useful in the research for a superior innovation. Here we abstract from such generalizations.

The loser of the R&D race gets zero payoff from its research activity. Furthermore, without loss of generality, in what follows we normalize the social benefit of success to $B=1$.

3.1. Equilibria in the IP Subgame

To find the subgame perfect Nash equilibrium (SPNE) of the game depicted in Figure 1, we begin with the subgames that start when R&D outcomes become known. Once the equilibrium payoffs from the IP subgames are determined, the game reduces to the one in Dasgupta and Maskin (1987) discussed earlier. For three of the possible four outcomes the situation is trivial. For the event (F,F), where both firms fail to innovate, the game ends with both firms obtaining a zero payoff. For the events (S,F) and (F,S), on the other hand, only one firm succeeds. The successful firm obtains a payoff $\delta(T)$ with patenting and a payoff $\gamma(z)$ with trade secrecy, and thus the IP choice revolves around $\max\{\gamma(z), \delta(T)\}$. The unsuccessful firm gets zero payoff.

For event (S,S), when both firms are successful with the invention, we have a simultaneous-move game for the firms' choice of IP protection mode. We assume that, if both firms try to patent, each firm has an equal chance of getting priority. If both choose trade secret protection, they will engage in a duopoly competition as long as the secret does not leak out.[9] If one of the firms decides to keep secret, it can of course be excluded whenever the other inventor decides to patent (the patenting firm would get the full reward). The payoff matrix in Table 1 summarizes the firms' IP subgame, where the parameter $\mu \in (0,1)$ captures the profit dissipation due to the competition that arises when both firms elect to use trade secrets (e.g., the joint profit of duopolists is lower than that of a monopolist).

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[9] We are implicitly assuming that the probability distribution of the trade secret duration does not depend on the number of secret holders.

Note that if $\delta(T) > \frac{\mu}{2}\gamma(z)$, the profile (Patent, Patent) is the unique Nash equilibrium. In particular, if $\mu\gamma(z) \le \delta(T)$, this equilibrium is Pareto efficient. If $\frac{\mu}{2}\gamma(z) < \delta(T) < \mu\gamma(z)$, the IP game is of the prisoner's dilemma type and the unique Nash equilibrium (Patent, Patent) yields a lower payoff (to both firms) than the profile (Secret, Secret). If $\delta(T) \le \frac{\mu}{2}\gamma(z)$, on the other hand, we have a coordination game that admits two pure-strategy Nash equilibria, i.e., the profiles in which both firms patent and that in which both firms choose the trade secret. In this case, we also have a mixed-strategy Nash equilibrium. Specifically, whenever $\delta(T) < \frac{\mu}{2}\gamma(z)$, the (symmetric) non-degenerate mixed strategy equilibrium is defined by $\sigma^* = \left[\delta(T)/\left(\mu\gamma(z) - \delta(T)\right)\right]$ for both players, where σ^* denotes the probability assigned to the pure strategy "Secret" (such that $1-\sigma^*$ is the probability assigned to the pure strategy "Patent").[10] We can summarize the foregoing analysis in the following:

Lemma 2. *In the IP subgame that follows the event* (S,S) *,(i) For* $\delta(T) \ge \mu\gamma(z)$ *there is a unique Nash equilibrium where both firms patent, and this equilibrium is Pareto efficient. (ii) For* $\mu\gamma(z) > \delta(T) > \mu\gamma(z)/2$ *there is a unique Nash equilibrium where both firms patent, and this equilibrium is of the prisoner's dilemma type. (iii) For* $\mu\gamma(z)/2 \ge \delta(T)$ *there are two pure strategy equilibria—(Patent, Patent) and (Secret, Secret)—and a mixed strategy equilibria..*

Table 2 summarizes the equilibrium outcomes of the IP subgame. Note that, as μ decreases towards 0 (that is, the market competition between firms when both hold the trade secret dissipates profits more and more), the range of parameter where (Patent, Patent) is the unique Nash equilibrium

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[10] The mixed strategy solution is somewhat unappealing in our context because it implies that, as the strategy profile where both firms patent become less and less attractive, in equilibrium each firm puts

increases (in particular, the range for UNE-1 increases and that for UNE-2 decreases). Furthermore, the range of parameters where multiple equilibria arise also shrinks.

3.2. Impact on Firms' Research Paths

By introducing alternative modes of protection, we have made otherwise exogenous payoffs a function of IP choices. Once the payoffs associated with the equilibria discussed in Lemma 2 are obtained, the reduced game has the same structure as the one in Dasgupta and Maskin (1987). We can then exploit the comparative statics analysis that we discussed in Lemma 1 to obtain comparisons of alternative IP environments. Specifically, we can conclude the following.

Proposition 2. *Whenever* $\mu \in (0,1)$ *and* $\delta(T) < \gamma(z)$, *the availability of trade secret protection, in addition to patents, leads firms to select actions that decrease the correlation of R&D outcomes, as compared with the patent-only environment, although the correlation level still remains higher than the socially optimal level.*

Proof. The equilibrium payoffs of the IP subgame, under the patents-plus-trade-secret environment, are summarized in the last two columns of Table 2. By contrast recall that, in the patents-only environment, the expected payoff to the firms for the event (S,S) is $U_{SS}^{P} = \frac{1}{2}\delta(T)$ and the payoff to the successful firm for events (S,F) and (F,S) is $U_{S}^{P} = \delta(T)$. Hence, for the parameter range $\gamma(z) > \delta(T) > \mu\gamma(z)/2$, the availability of trade secret protection (in addition to patents) increases the winner's payoff for the events with only one successful firm while it leaves unchanged the payoff for the event when both firms succeed. By Lemma 1, therefore, the equilibrium correlation level must decline (i.e., the Nash equilibrium action a^{c} increases). For the parameter range $\mu\gamma(z)/2 \geq \delta(T)$ the

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more probability mass on the "Patent" strategy.

payoff associated with the event (S,S) depends on which particular equilibrium one considers. For the (Patent, Patent) equilibrium the outcome is exactly as for the $\gamma(z)>\delta(T)>\mu\gamma(z)/2$ parameter range. For the (Secret, Secret) equilibrium, the equilibrium payoffs under patent-plus-trade-secret environment is $U_{SS}^{P+S}=\frac{\mu}{2}\gamma(z)$ for event (S,S) and $U_{S}^{P+S}=\gamma(z)$ for the events with a single successful firm. Then, $\left(U_{SS}^{P+S}/U_{S}^{P+S}\right)=\frac{\mu}{2}<\left(U_{SS}^{P}/U_{S}^{P}\right)=\frac{1}{2}$ because $\mu\in(0,1)$, and hence the results of Lemma 1 apply to this domain as well. Finally, the mixed-strategy equilibrium payoff under event (S,S) cannot exceed that of the equilibrium (Secret, Secret), and therefore we again conclude that $\left(U_{SS}^{P+S}/U_{S}^{P+S}\right)<\left(U_{SS}^{P}/U_{S}^{P}\right)$. By Lemma 1, therefore, the equilibrium correlation level must decline.■

The equilibrium R&D choices of the firms, for the various regions of the parameter space that we discussed, are illustrated in Figure 2. Note that, whenever $\delta(T)<\gamma(z)$, (Patent, Patent) is a Nash equilibrium of the IP subgame. For this equilibrium the ratio U_{SS}^{P+S}/U_{S}^{P+S} is monotonically increasing in $\delta(T)$, and so the equilibrium competitive action for this environment, labeled a_{P+S}^{c}, is decreasing (i.e., R&D projects are more and more correlated). For the subset $\left(\mu\gamma(z)/2\right)<\delta(T)<\gamma(z)$ of this parameter range, the profile (Patent, Patent) is actually the unique Nash equilibrium, and the associated graph of a_{P+S}^{c} is represented by the green segment in Figure 2. When $\delta(T)=\gamma(z)$ the payoff ratio reaches its maximum value of $\frac{1}{2}$; this is the same as the patent-only environment, and thus $a_{P+S}^{c}=a_{P}^{c}$ for $\delta(T)\geq\gamma(z)$. For the domain $\delta(T)\leq\mu\gamma(z)/2$ we have two Nash equilibria in pure strategies. If the firms could coordinate on the (Secret, Secret) equilibrium, the payoff ratio would be $\left(U_{SS}^{P+S}/U_{S}^{P+S}\right)=\frac{\mu}{2}<\frac{1}{2}$, leading to the equilibrium outcome that equal the value of the solution in an hypothetical trade-secret-only environment, labeled a_{S}^{c} in

Figure 2. Note that the trade-secret-only environment would lead to an equilibrium correlation level that is lower than the patent-only environment. In fact, it is even lower than the equilibrium correlation level under the patent-plus-secrecy environment whenever $\delta(T) > \mu\gamma(z)$. For the parameter range $\delta(T) \leq \mu\gamma(z)/2$ we also have a mixed strategy Nash equilibrium, the equilibrium outcome of which are depicted by the red segment.

We should stress that the main point of Proposition 2 does not rely on the assumption that $\mu < 1$. Indeed, were one to make the (questionable) assumption that $\mu = 1$, the parameter range $(\gamma(z)/2) < \delta(T) < \gamma(z)$ would still support our conclusion (see Figure 2). We can also note that the parameter space associated with a unique equilibrium in the IP subgame could be extended by appealing to notions that select among pure-strategy Nash equilibria. Particularly attractive, in our case, is the notion of risk-dominant equilibrium (RDE) introduced by Harsanyi and Selten (1988). In our 2×2 symmetric game, if both players strictly prefer the same action when each assumes that the opponent randomizes evenly between the two available actions, then the profile in which they play that action is the risk-dominant equilibrium. (Fudenberg and Tirole, 1991).[11] It follows that, if $\frac{\mu}{3}\gamma(z) < \delta(T) \leq \frac{\mu}{2}\gamma(z)$, then the profile (Patent, Patent) is the (unique) RDE, thereby extending the parameter range where the competitively chosen diversification efforts are decreasing in $\gamma(z)$ (i.e., the green segment in Figure 2). Conversely, if $\delta(T) < \frac{\mu}{3}\gamma(z)$ the RDE profile is (Secret, Secret) and, for the case $\delta(T) = \frac{\mu}{3}\gamma(z)$, neither pure strategy equilibrium is dominating (which makes the mixed strategy equilibrium perhaps more meaningful at this point). Table 3 presents the equilibrium payoffs and Figure 4 illustrates the equilibrium diversification efforts for different parameter space as RDE

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[11] The basic idea is that, when a player does not know which equilibrium is selected by the other player, she will play the strategy of the less risky equilibrium. Risk-dominance as an equilibrium selection criterion in 2×2 games also is supported by the global games analysis of Carlsson and van Damme (1993), the results of which are extended to supermodular games by Frankel, Morris and Pauzner (2003).

notion is appealed in the relevant parameter range.

An additional result that is worth emphasizing in this model concerns the ability of the social planner to affect firms' choices by altering the parameters T and z that index the strength of IPR protection.

Proposition 3. *In the patent-only environment the social planner cannot affect the firms' R&D diversification choices by choosing the patent length* T. *In the patent-plus-trade-secret environment, on the other hand, the social planner may be able to induce firms to diversify towards social optimum by providing a relatively weaker protection to patents (or stronger protection for trade-secrets).*

Proof. The first part of the proposition follows directly from observing that, in the patent-only environment, the payoff ratio $\left(U_{SS}^{P}/U_{S}^{P}\right)=\frac{1}{2}$ is independent of patent length T. In the patent-plus-secrecy environment, on the other hand, a_{P+S}^{c} monotonically increases as T decreases for the unique Nash equilibrium of the parameter range $\gamma(z)>\delta(T)>\mu\gamma(z)/2$.■

For a similar argument, the social planner cannot affect R&D correlation in the other polar case, the trade-secret-only environment, by choosing the strength of trade secret protection (as indexed by the leak parameter z). Hence, in our setting, the strength of IPR protection can be an effective policy instrument, to affect the firms' equilibrium R&D correlation level, only if multiple protection instruments are available. Thus, our analysis provides another justification for the optimality of a finite patent length, distinct from the classic trade-off between dynamic incentive benefits and static efficiency losses analyzed by Nordhaus (1969) and others.

4. An Example

The relationship between the equilibrium correlation levels, the different values of the leak parameter, and the behavior of the correlation level under different solution concepts as patent length varies can be illustrated with the following example. First, we parameterize the correlation coefficient as $\rho \equiv 1-\frac{1}{2}(a_1+a_2)$. Thus, as in Dasgupta and Maskin (1987) we consider the case of non-negative correlation only. Next, the unconditional probability functions are specified as $p_i(a_i)=\frac{1}{4}-\frac{1}{8}a_i^2$. Note that this implies $p_i(a_i)\in[0,\frac{1}{2}]$ and, given our parameterization of correlation, the condition $p_i(a_i)\in[0,\frac{1}{2}]$ is sufficient to ensure that the covariance term is decreasing in the actions a_1 and a_2 (see also Appendix A.1.1). Thus, this parameterization satisfies the basic assumptions of our model. The resulting social planner's objective function, equation (2), is in fact concave for the domain of interest. To solve for the firms' noncooperative choices, we set $r=0.04$ and, consistent with the assumed normalization $B=1$, set $b=r$. Finally, we set $\mu=8/9$ (as would result, for example, from a textbook example of Cournot competition with linear demands).

Having computed the optimal R&D choices, in Figure 3 we report the implied correlation coefficient ρ under various conditions regarding $\gamma(z)$ and $\delta(T)$. Specifically, here we fix the patent length as $T=20$ years (as is the case in virtually all jurisdictions), so that the fraction of social surplus that is offered by patent protection is $\delta(20)=0.55$, and then consider various levels of the trade secret parameter $\gamma(z)$. The socially optimal correlation level for this example turns out to be $\rho^*=0.48$. If IPR protection were available only through patents, the firms' noncooperative action choices results in $\rho^P=0.76$. When trade secrets are available, in addition to patents, then we need to differentiate according to the parameter space. For values of z such that $\gamma(z)\le\delta(20)$, trade secret protection is not effective and the correlation level is calculated as $\rho^{P+S}=\rho^P=0.76$. When $\gamma(z)$

exceeds $\delta(20)$, trade secret protection becomes relevant and the Nash equilibrium correlation level decreases, reaching a minimum of 0.63 (when $\gamma(z)=1$). For the range $\delta(20)<\gamma(z)\leq 1$, the profile where both firms patent is actually the unique Nash equilibrium. In fact, given the chosen levels of the parameters, here it is always the case that $\frac{\mu}{2}\gamma(z)<\delta(20)$, $\forall z\in[0,\infty)$ and $\forall\mu\in(0,1)$, and thus the case of multiple equilibria for the IP subgame does not arise. This equilibrium is of the prisoner's dilemma type for $\gamma(z)>\delta(20)/\mu$, that is for $\gamma(z)>0.62$. Thus, the profit-dissipation parameter $\mu\in(0,1)$ does not affect ρ^{P+S} in Figure 3 but only the hypothetical correlation level that would attain in the trade-secret-only environment, say ρ^{S} and, from the foregoing, $\rho^{S}=0.73<\rho^{P}$.

5. Conclusion

We have shown that the availability of multiple modes of protection—specifically trade secrets and patents—can affect the equilibrium outcome of competitively chosen diversification efforts in a parallel research contest. In particular, the availability of trade secrets in addition to patents can push the market outcome towards the social optimum as far as the choice of correlation among R&D projects is concerned. Therefore, considering a generic winner-takes-all contest (with an implicit single mode of protection) in studying the correlation level of firms' R&D activities may miss an important institutional feature and may overestimate the bias inherent in competitive parallel research contests.

Another implication of the model that we have studied is that it is only when multiple modes of protection are present that the competitively chosen R&D diversification efforts can be affected by the patent length. In reality, of course, patent length is fixed by law and, following the implementation of the TRIPS agreement of the World Trade Organization, it is the same (20 years) for all signatory countries. But what matters here is the strength of IPR protection offered by patents relative to that of trade secrets, and the latter are quite a bit more variable because they are rooted in civil law. Furthermore, the strength of trade secret protection may vary across technology fields because it depends crucially of the feasibility of reverse engineering (admissible under trade secret protection). Hence, in some fields at least, the availability of trade secret protection may be critical for the nature of competitively chosen R&D activities and may beneficially affect firms' R&D diversification efforts.

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Table 1. Payoff matrix of IP protection subgame

		Firm 2	
		Trade Secret	Patent
Firm 1	Trade Secret	$\frac{\mu}{2}\gamma(z)$, $\frac{\mu}{2}\gamma(z)$	0 , $\delta(T)$
	Patent	$\delta(T)$, 0	$\frac{1}{2}\delta(T)$, $\frac{1}{2}\delta(T)$

Table 2. Parametric domain, equilibrium IP strategies and outcomes with both patents and trade secrets

Parametric domain	Event (S,S): both firms are successful			Events (S,F) or (F,S)
	Equilibrium profile(s)	Type of equilibrium	Equilibrium payoff(s)	Winner's payoff
$\delta(T) \geq \gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\delta(T)$
$\gamma(z) > \delta(T) \geq \mu\gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z) > \delta(T) > \mu\gamma(z)/2$	(Patent , Patent)	UNE-2	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z)/2 \geq \delta(T)$	(Patent , Patent) (Secret , Secret) $(\sigma^*, 1-\sigma^*)$	MNE	$\frac{1}{2}\delta(T)$ $\frac{\mu}{2}\gamma(z)$ $\frac{\mu\gamma(z)\delta(T)}{2(\mu\gamma(z)-\delta(T))}$	$\gamma(z)$

Notes: UNE-1 = Unique Nash equilibrium (Pareto efficient);

UNE-2 = Unique Nash equilibrium (prisoner's dilemma);

MNE = Multiple Nash equilibria, where the mixed strategy equilibrium is:

$$\sigma^* = \frac{\delta(T)}{\mu\gamma(z)-\delta(T)}.$$

Table 3. Parametric domain and equilibrium IP strategies and outcomes

Parametric domain	Event (S,S): both firms are successful			Events (S,F) or (F,S)
	Equilibrium profile	Type of equilib-rium	Equilibrium payoff	Winner's payoff
$\delta(T) \geq \gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\delta(T)$
$\gamma(z) > \delta(T) \geq \mu\gamma(z)$	(Patent , Patent)	UNE-1	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z) > \delta(T) > \mu\gamma(z)/2$	(Patent , Patent)	UNE-2	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\mu\gamma(z)/2 \geq \delta(T) > \mu\gamma(z)/3$	(Patent , Patent)	RDE	$\frac{1}{2}\delta(T)$	$\gamma(z)$
$\delta(T) = \mu\gamma(z)/3$	$(\sigma,1-\sigma)=(1/2,1/2)$	MSE	$\frac{\mu}{4}\gamma(z)$	$\gamma(z)$
$\mu\gamma(z)/3 > \delta(T)$	(Secret , Secret)	RDE	$\frac{\mu}{2}\gamma(z)$	$\gamma(z)$

Notes: UNE-1 = Unique Nash equilibrium (Pareto efficient);
UNE-2 = Unique Nash equilibrium (prisoner's dilemma);
RDE = Risk-dominant equilibrium; and,
MSE = Mixed strategy equilibrium.

Figure 1. The model with both patents and trade secrets

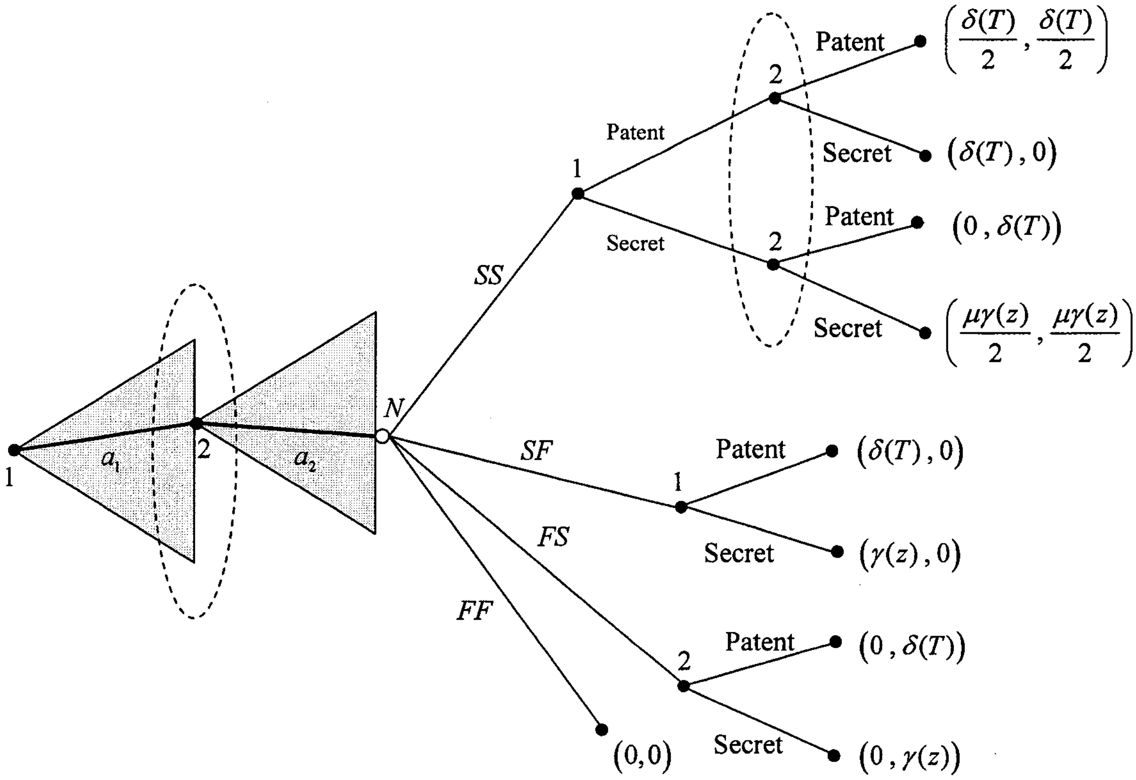


Figure 2. Correlation of R&D projects and Solution Concepts

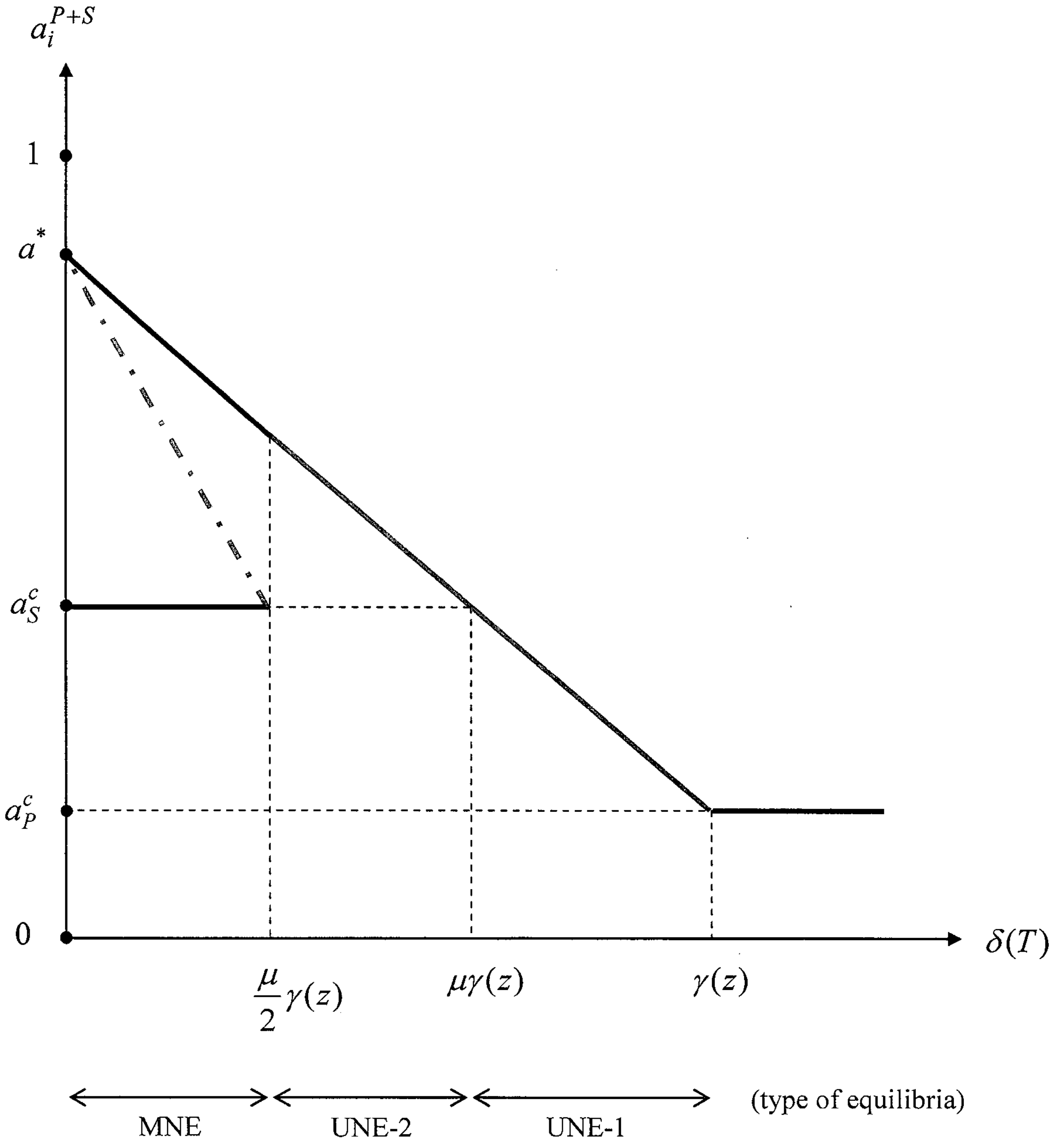


Figure 3. Example

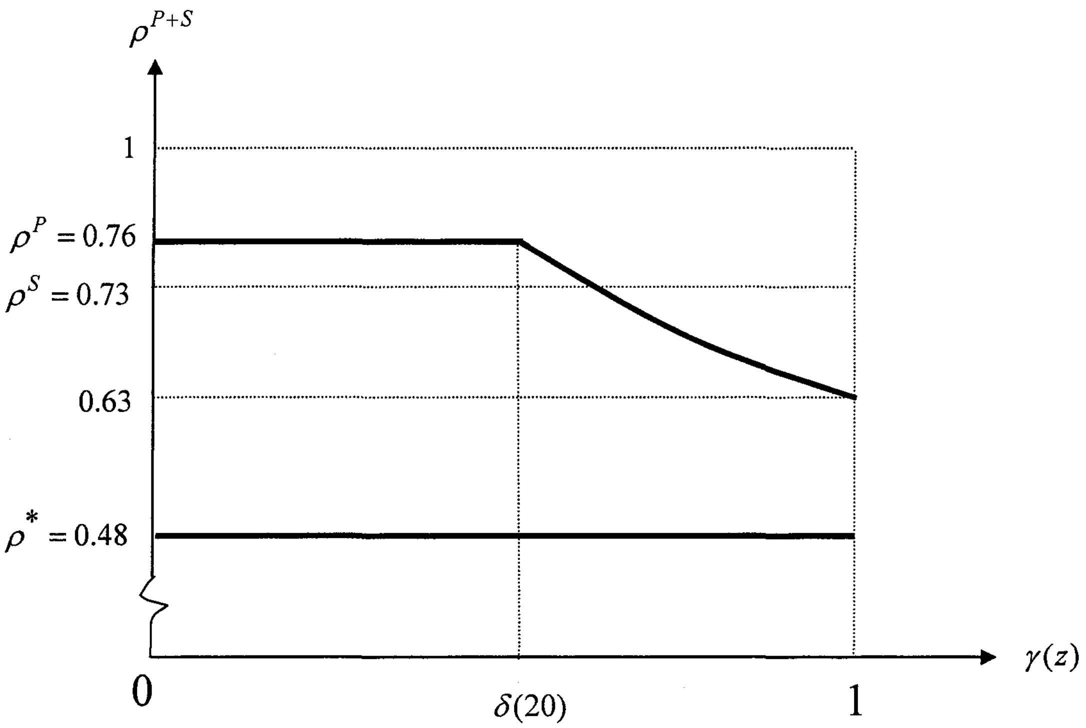
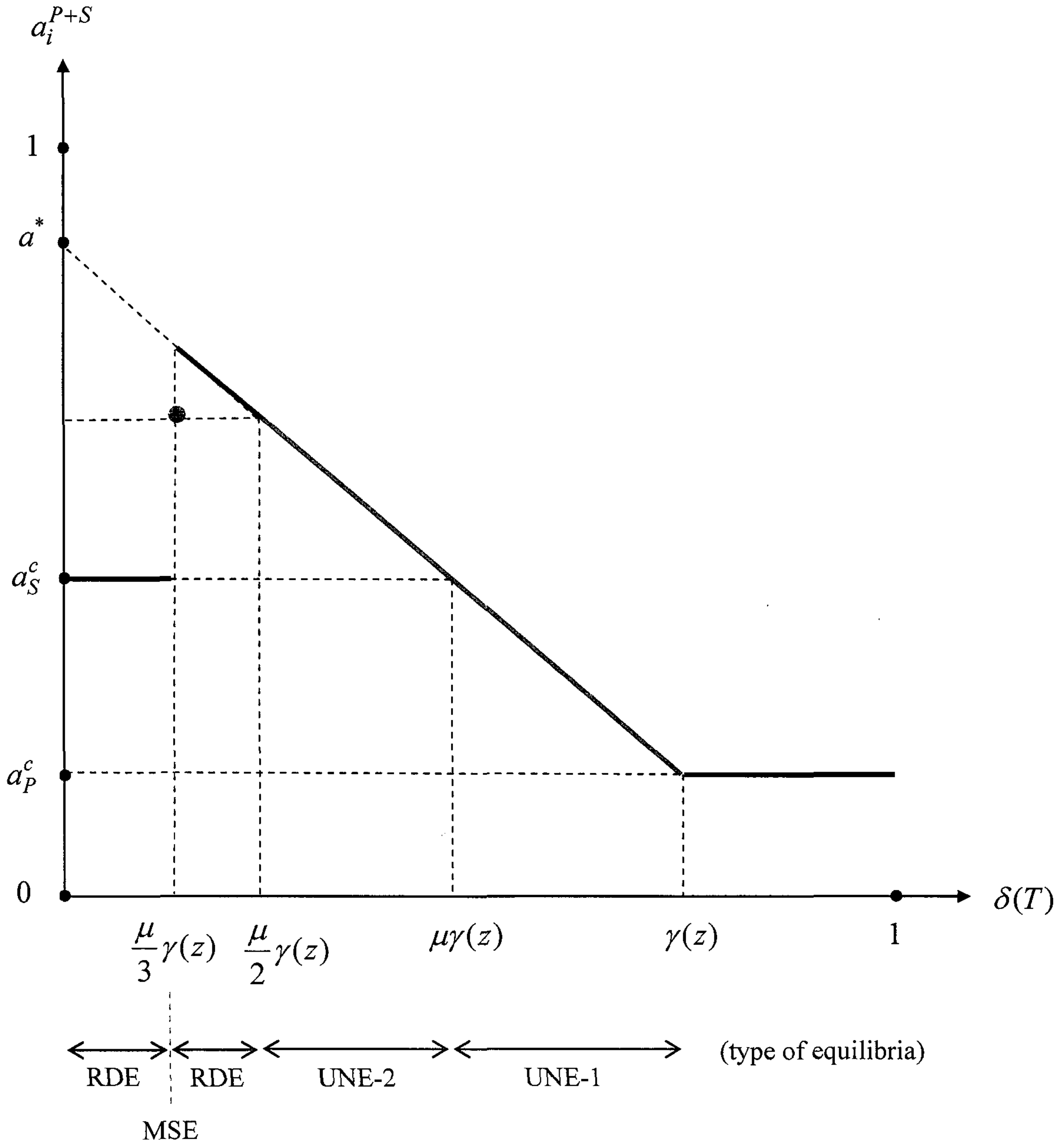


Figure 4


a_i^{P+S}
1
a^*
a_S^c
a_P^c
0
$\delta(T)$
$\frac{\mu}{3}\gamma(z)$
$\frac{\mu}{2}\gamma(z)$
$\mu\gamma(z)$
$\gamma(z)$
1
(type of equilibria)
RDE
RDE
UNE-2
UNE-1
MSE

Appendix to Chapter 2.

In this section, we economize on the notation as follows; $p_1 \equiv p(a_1)$, $p_2 \equiv p(a_2)$, $p_{FF} \equiv prob\{FF\}$, $p_{SF} \equiv prob\{SF\}$, $p_{FS} \equiv prob\{FS\}$, and $p_{SS} \equiv prob\{SS\}$.

A.1. On the Assumption 1:

A.1.1. The part on the covariance term:

Recall that covariance is defined as $Cov(X_1,X_2) \equiv \rho\sqrt{p_1(1-p_1)p_2(1-p_2)}$ and written as the function of project choices, $C(a_1,a_2) = \rho(a_1,a_2)\sqrt{p(a_1)[1-p(a_1)]p_2[1-p(a_2)]}$ for all $(a_1,a_2) \in [0,1]\times[0,1]$. Because covariance is assumed to be non-negative (as in Dasgupta and Maskin, 1987) and $C(1,1)=0$, it implies that $\rho(a_1,a_1) \geq 0$ and $\rho(1,1)=0$, respectively. Defining $\bar{\rho} = \rho(0,0) \leq 1$ as the maximum positive correlation and $\bar{p} \equiv p(0)$ as the maximum unconditional probability of success, one can obtain $Cov(0,0) = \bar{\rho}\bar{p}(1-\bar{p})$. Moreover, the covariance function is symmetric in project choices, that is $C(a_1,a_2) = C(a_2,a_1)$, $\forall\,(a_1,a_2) \in [0,1]\times[0,1]$ as the success probability function $p(\cdot)$ is the same for both firms. Because covariance is decreasing in either project choices a_i, its first order derivative (F.O.D.) with respect to project choices a_i must be non-positive. Without loss of generality, focus on the F.O.D. of covariance with respect to a_1:

$$\frac{\partial Cov(X_1,X_2)}{\partial a_1} = \frac{\partial(\rho\sqrt{Var(X_1)Var(X_2)})}{\partial a_1} = \sqrt{Var(X_2)}(\frac{\partial(\rho\sqrt{Var(X_1)})}{\partial a_1})$$

$$= \sqrt{Var(X_2)}(\frac{\partial \rho}{\partial a_1}\sqrt{Var(X_1)} + \rho\frac{1}{2}\frac{\frac{\partial Var(X_1)}{\partial a_1}}{\sqrt{Var(X_1)}})$$

, which can be further arranged as

$$\frac{\partial Cov(X_1,X_2)}{\partial a_1}=\sqrt{Var(X_2)}\sqrt{Var(X_1)}\left(\frac{\partial \rho}{\partial a_1}+\rho\frac{1}{2}\frac{\frac{\partial (Var(X_1))}{\partial a_1}}{Var(X_1)}\right) \tag{A.1}$$

The symmetric version of this condition applies for firm 2. Recall that $\rho \geq 0$. Because

$$\frac{\partial (Var(X_1))}{\partial a_1}=\frac{\partial p_1}{\partial a_1}(1-2p_1) \tag{A.2}$$

In particular, if $p(a)\leq \frac{1}{2}$ for all a in the domain (as is assumed in Dasgupta and Maskin, 1987 and in the Example), then $\frac{\partial Var(X_i)}{\partial a_i}\leq 0$. Hence, assuming $\frac{\partial \rho}{\partial a_i}<0$ as in the Example would be sufficient to sign the derivative of covariance in a_i as negative. Finally, if $p(a_i)>\frac{1}{2}$ for some a_i in the domain, then $\frac{\partial Var(X_i)}{\partial a_i}>0$. Hence, it would be necessary to assume $\frac{\partial \rho}{\partial a_i}<0$ to sign the derivative of covariance in a_i as negative, which, however, would be no longer sufficient. One would need a stronger condition in that case. Specifically, for $i=1,2$

$$\frac{1}{2}\frac{\frac{\partial Var(X_i)}{\partial a_i}}{Var(X_i)}<-\frac{\partial \rho}{\partial a_i} \tag{A.3}$$

A.1.2 The part on the curvature of the probability of event (F,F) :

In the following, we discuss the implications of this assumption: The assumption that the probability of event (F,F) in (1.d), denoted by p_{FF} is strictly convex is equivalent to assuming that the objective function of the social planner in equation (2) is strictly concave. The assumption on the curvature of the probability of event (F,F) implies that the Hessian matrix for p_{FF} is positive semi definite, which in turn has the following implications:

Lemma A.1 p_{SF} *is concave in* a_1 *and* p_{FS} *is concave in* a_2 .

Proof Because the Hessian matrix for p_{FF} is positive semi definite, $\frac{\partial^2 p_{FF}}{\partial a_1^2} \geq 0$ and $\frac{\partial^2 p_{FF}}{\partial a_2^2} \geq 0$. Using the relations $p_{FF} = 1 - p_{SF} - p_2 = 1 - p_{FS} - p_1$, which can be obtained from equation (1), it follows that $\frac{\partial^2 p_{FF}}{\partial a_1^2} = -\frac{\partial^2 p_{SF}}{\partial a_1^2} \geq 0$ and $\frac{\partial^2 p_{FF}}{\partial a_2^2} = -\frac{\partial^2 p_{FS}}{\partial a_2^2} \geq 0$.

Lemma A.2 $\frac{\partial^2 p_{SF}}{\partial a_1^2}\frac{\partial^2 p_{FS}}{\partial a_2^2} - \left[\frac{\partial^2 p_{SF}}{\partial a_2 \partial a_1}\right]^2 \geq 0$.

Proof Because the Hessian matrix for p_{FF} is positive semi definite, $\frac{\partial^2 p_{FF}}{\partial a_1^2}\frac{\partial^2 p_{FF}}{\partial a_2^2} - \left[\frac{\partial^2 p_{FF}}{\partial a_1 \partial a_2}\right]^2 \geq 0$ and together with the relations $p_{FF} = 1 - p_{SF} - p_2 = 1 - p_{FS} - p_1$, the claim follows. Note also that $\frac{\partial^2 p_{FF}}{\partial a_1 \partial a_2} = -\frac{\partial^2 p_{SF}}{\partial a_2 \partial a_1} = -\frac{\partial^2 p_{FS}}{\partial a_2 \partial a_1} = -\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1}$.

Corollary A.1 *The objective functions of the firms (equation (4.1) for firm 1) are strictly concave.*

Proof Twice differentiate the objective function of firm 1 (equation (5.1)) and use the relation that $p_{SS} = p_1 - p_{SF}$ to obtain

$$\frac{\partial^2 V_1}{\partial a_1^2} = U_{SS}\underbrace{\frac{\partial^2 p_1}{\partial a_1^2}}_{<0} + \underbrace{(U_S - U_{SS})}_{>0}\underbrace{\frac{\partial^2 p_{SF}}{\partial a_1^2}}_{\leq 0 \text{ by Lemma A.1}} < 0$$

The case for firm 2 is symmetric.

Corollary A.2 $\frac{\partial^2 V_1}{\partial a_1^2}\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2}\frac{\partial^2 V_2}{\partial a_2 \partial a_1} > 0$

Proof Obtain the following expressions by differentiating objective functions of the firms (equation (4.1) for firm 1) and using the relations $p_{FF} = 1 - p_{SF} - p_2 = \quad 1 - p_{FS} - p_1$:

$$\frac{\partial^2 V_1}{\partial a_1^2} = U_S \frac{\partial^2 p_1}{\partial a_1^2} + (U_S - U_{SS}) \frac{\partial^2 p_{SF}}{\partial a_1^2}$$

$$\frac{\partial^2 V_2}{\partial a_2^2} = U_S \frac{\partial^2 p_2}{\partial a_1^2} + (U_S - U_{SS}) \frac{\partial^2 p_{FS}}{\partial a_2^2}$$

$$\frac{\partial^2 V_1}{\partial a_2 \partial a_1} = \frac{\partial^2 V_2}{\partial a_2 \partial a_1} = (U_{SS} - U_S)(\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1})$$

Define

$$\Delta \equiv \frac{\partial^2 V_1}{\partial a_1^2} \frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2} \frac{\partial^2 V_2}{\partial a_2 \partial a_1} \tag{A.4}$$

Plug the corresponding expressions above in the preceding equation for Δ and obtain

$$\Delta = (U_S)^2 \underbrace{\frac{\partial^2 p_1}{\partial a_1^2}}_{<0} \underbrace{\frac{\partial^2 p_2}{\partial a_2^2}}_{<0} + \underbrace{(U_S - U_{SS})}_{>0} U_S \underbrace{\frac{\partial^2 p_{FS}}{\partial a_2^2}}_{<0} \underbrace{\frac{\partial^2 p_1}{\partial a_1^2}}_{<0}$$

$$+ \underbrace{(U_S - U_{SS})}_{>0} U_S \underbrace{\frac{\partial^2 p_{SF}}{\partial a_1^2}}_{<0} \underbrace{\frac{\partial^2 p_2}{\partial a_2^2}}_{<0}$$

$$+ (U_S - U_{SS})^2 \left[\underbrace{\frac{\partial^2 p_{SF}}{\partial a_1^2} \frac{\partial^2 p_{FS}}{\partial a_2^2} - (\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1})^2}_{\geq 0 \text{ by Lemma A.2}} \right] > 0 \ .$$

Corollary A.3 *Nash Equilibrium for firms' project choice game in the market exists, unique and globally asymptotically stable.*

Proof Firstly, strategy sets of players, are closed, convex, bounded, and orthogonal, (that is, the set of feasible strategy profiles is the direct product of individual player's strategy spaces) as $a_i \in [0,1]$ for $i \in \{1,2\}$. Moreover, from Corollary A.1, the objective functions of firms are continuous and concave in their respective project choices, therefore Nash equilibrium exists (Rosen, 1965).[12] From Corollaries 1 and 2, the Jacobian of the matrix of best response functions is negative definite, which is sufficient for the remaining claims (Rosen, 1965).[13]

A.2 Sufficient conditions for interior solutions

In the following, we provide sufficient conditions (equations (A.8) and (A.9) below) for interior solutions. Let $\left(a^*,a^*\right)$ and $\left(a^c,a^c\right)$ be the solutions to the social planner's and firms' problems (equations (2) and (4), respectively). For these solutions to lie in the interior of the domain, that is, $a^* \in (0,1)$ and $a^c \in (0,1)$ the following conditions are sufficient:

$$\frac{\partial V_1(a_1,a_2)}{\partial a_1}\Big|_{a_1=a_2=0} > 0 \tag{A.5}$$

$$\frac{\partial p_{SF}}{\partial a_1}\Big|_{a_1=a_2=1} < 0 \tag{A.6}$$

Using the relation $p_{SF} = p_1 - p_{SS}$ in equation (5.1) yields

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[12] Rosen, J. B., 1965, Existence and Uniqueness of Equilibrium Points for Concave N-Person Games *Econometrica,* 33(3), 520-534.

[13] Rosen (1965) defines an appropriate dynamic model for concave n-person games (that is, games in which each player's payoff function is concave in his own strategy), where starting from any point in the domain each player changes its own strategy in the direction of gradient so that its own payoff function would increase as other players sticked to their current strategies, which defines a set of differential equations. Whenever the conditions for uniqueness of Nash equilibrium are satisfied, he shows that the system of differential equations will always converge to the unique equlibrium point of the original game. Therefore, the unique Nash equilibrium of the game is globally asymptotically stable.

$$\frac{\partial V_1}{\partial a_1}|_{a_1=a_2=0} = U_{SS}\underbrace{\frac{\partial p_1}{\partial a_1}|_{a_1=0}}_{<0} + \underbrace{(U_S - U_{SS})}_{>0}\underbrace{\frac{\partial p_{SF}}{\partial a_1}|_{a_1=a_2=0}}_{?} \tag{A.7}$$

Although assuming that

$$\frac{\partial p_{SF}}{\partial a_1}|_{a_1=a_2=0} > 0$$

is sufficient for the social planner's solution to lie away from origin (see equation (3)), it is only necessary condition for solution to the firms' problem to lie in the interior. Now,

$$\frac{\partial p_{SF}}{\partial a_1} = \underbrace{\frac{\partial p_1}{\partial a_1}}_{<0}(1 - p_2) - \underbrace{\frac{\partial Cov(X_1, X_2)}{\partial a_1}}_{<0}$$

Plugging the corresponding expression for the first order derivative of covariance from equation (A.1) in the preceding equation yields

$$\frac{\partial p_{SF}}{\partial a_1} = \underbrace{\frac{\partial p_1}{\partial a_1}}_{<0}[(1 - p_2) - \rho\frac{1}{2}\frac{(1 - 2p_1)}{Var(X_1)}\sqrt{Var(X_2)}\sqrt{Var(X_1)}]$$
$$-\sqrt{Var(X_2)}\sqrt{Var(X_1)}\frac{\partial \rho}{\partial a_1}$$

Evaluating the preceding equation at $a_1 = a_2 = 0$ by noting that $\rho(a_1 = 0, a_2 = 0) = \bar{\rho} \le 1$ and $\bar{p} \equiv p(0)$ yields

$$\frac{\partial p_{SF}}{\partial a_1}|_{a_1=a_2=0} = (\frac{\partial p_1}{\partial a_1}|_{a_1=0})[(1 - \bar{p}) - \frac{\bar{\rho}}{2}(1 - 2\bar{p})] - (1 - \bar{p})\bar{p}\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}$$
$$= \frac{\partial p_1}{\partial a_1}|_{a_1=0}\underbrace{[(1 - \bar{p})(1 - \frac{\bar{\rho}}{2}) + \frac{\bar{\rho}}{2}\bar{p})]}_{\equiv\psi} - (1 - \bar{p})\bar{p}\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}$$

Plug the preceding equation in (A.7) and obtain

$$\frac{\partial V_1}{\partial a_1}|_{a_1=a_2=0} = U_{SS}\underbrace{\frac{\partial p(a_1)}{\partial a_1}|_{a_1=0}}_{<0} + \underbrace{(U_S - U_{SS})}_{>0}[\frac{\partial p_1}{\partial a_1}|_{a_1=0}\,\psi - (1-\bar{p})\bar{p}\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}]$$

$$= (U_{SS} + (U_S - U_{SS})\psi)\frac{\partial p(a_1)}{\partial a_1}|_{a_1=0} - (U_S - U_{SS})(1-\bar{p})\bar{p}\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}$$

$$= (\psi U_S + U_{SS}(1-\psi))\frac{\partial p(a_1)}{\partial a_1}|_{a_1=0} - (U_S - U_{SS})(1-\bar{p})\bar{p}\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}$$

Now, the condition (A.5) is equivalent to

$$-\frac{\partial p_1}{\partial a_1}|_{a_1=0} < \frac{(U_S - U_{SS})}{\psi U_S + (1-\psi)U_{SS}}(1-\bar{p})\bar{p}(\underbrace{-\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}}_{<0})$$

, which can be arranged as

$$-\frac{\partial p_1}{\partial a_1}|_{a_1=0} < \frac{(\frac{U_S}{U_{SS}} - 1)}{\psi\frac{U_S}{U_{SS}} + (1-\psi)}(1-\bar{p})\bar{p}(\underbrace{-\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}}_{<0})$$

Because it is assumed that $U_S \geq 2U_{SS} > 0$, it is sufficient to assume that

$$-\frac{\partial p_1}{\partial a_1}|_{a_1=0} < \frac{1}{1+\psi}(1-\bar{p})\bar{p}(\underbrace{-\frac{\partial \rho}{\partial a_1}|_{a_1=a_2=0}}_{<0}) \qquad \text{(A.8)}$$

Recall that $\psi \equiv (1-\bar{p})(1-\frac{\bar{\rho}}{2}) + \frac{\bar{\rho}}{2}\bar{p}) < 1$ as $0 < \bar{p} < 1$ and $0 < \bar{\rho} \leq 1$.

Now, focus on the condition in (A.6): It is sufficient for both solutions to social planner's and firms' problems to lie away from 1. For the social planner's problem, condition (A.6) means that the first order derivative (F.O.D.) of its objective function with respect to a_1 is negative at $a_1 = a_2 = 1$ (see equation (3)). For firms' problem in a market setting, condition in (A.6) is sufficient as follows: Use the relation $p_{SF} = p_1 - p_{SS}$ and evaluate the F.O.D. of firm 1's objective function (left hand side of equation (5.1) for firm 1) at $a_1 = a_2 = 1$ and obtain

$$\frac{\partial V_1}{\partial a_1}\Big|_{a_1=a_2=1} = U_{SS}\underbrace{\frac{\partial p(a_1)}{\partial a_1}\Big|_{a_1=1}}_{<0} + \underbrace{(U_S - U_{SS})}_{>0}\ \underbrace{\frac{\partial p_{SF}}{\partial a_1}\Big|_{a_1=a_2=1}}_{<0 \text{ by condition in (A.5)}} \quad < 0$$

Now, recall that $\underline{p} \equiv p(1) \geq 0$, $\rho(a_1 = 1, a_2 = 1) = 0$, and $Cov(X_1, X_2) \equiv \rho\sqrt{p_1(1-p_1)p_2(1-p_2)}$. Note that if $\underline{p} \equiv p(1) = 0$, then $Cov(X_1, X_2)$ is not differentiable with respect to project choices at $a_1 = 1, a_2 = 1$. Therefore, we need to assume that $\underline{p} \equiv p(1) > 0$. Then, evaluating equation (A.6) at $a_1 = a_2 = 1$ yields

$$\frac{\partial p_{SF}}{\partial a_1}\Big|_{a_1=a_2=1} = (1-\underline{p})\frac{\partial p(a_1)}{\partial a_1}\Big|_{a_1=1} - \underline{p}(1-\underline{p})\frac{\partial \rho}{\partial a_1}\Big|_{a_1=a_2=1}$$

Then, the condition (A.6) is equivalent to

$$-\frac{\partial p(a_1)}{\partial a_1}\Big|_{a_1=1} > (\underbrace{-\frac{\partial \rho}{\partial a_1}\Big|_{a_1=a_2=1}}_{<0})\underline{p} \qquad \text{(A.9)}$$

A.3. 1 On the slopes of best response functions

Project choices can be strategic complements or substitutes, which is admissible as the Nash Equilibrium is unique and globally asymptotically stable. In the following, we provide an analysis of the slopes of best response functions:

Without loss of generality consider firm 1. The best response function of firm 1 is defined by the identity

$$\frac{\partial V_1(a_1^c(a_2), a_2)}{\partial a_1} \equiv 0$$

The slope for the best response function of firm 1 is obtained by differentiating this identity

$$\frac{a_1^c(a_2)}{\partial a_2} = -\frac{\frac{\partial^2 V_1(a_1^c(a_2),a_2)}{\partial a_2 \partial a_1}}{\frac{\partial^2 V_1(a_1^c(a_2),a_2)}{\partial a_1^2}}$$

Its sign is determined by the sign of numerator because the denominator is negative by Corollary A.1.

Now,

$$\frac{\partial^2 V_1(a_1^c(a_2),a_2)}{\partial a_2 \partial a_1} = \frac{\partial}{\partial a_2}\frac{\partial}{\partial a_1}(U_{SS}p_{SS} + U_S p_{SF})$$

Because $p_{SF} = p_1 - p_{SS}$,

$$\begin{aligned}\frac{\partial^2 V_1(a_1^c(a_2),a_2)}{\partial a_2 \partial a_1} &= \frac{\partial}{\partial a_2}\frac{\partial}{\partial a_1}((U_{SS} - U_S)p_{SS} + U_S p_1 \\ &= \underbrace{(U_{SS} - U_S)}_{<0}\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1}\end{aligned}$$

Therefore,

$$\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1} > 0 \Leftrightarrow \text{ Project choices are strategic substitutes}$$

$$\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1} < 0 \Leftrightarrow \text{ Project choices are strategic complements}$$

Now,

$$\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1} = \underbrace{\frac{\partial p_1}{\partial a_1}}_{<0}\underbrace{\frac{\partial p_2}{\partial a_2}}_{<0} + \underbrace{\frac{\partial^2 Cov(X_1,X_2)}{\partial a_2 \partial a_1}}_{?} \qquad \text{(A.10)}$$

Observe that if $\frac{\partial^2 Cov(X_1,X_2)}{\partial a_2 \partial a_1} \geq 0$, then project choices are strategic substitutes. Otherwise, the net effect matters. Differentiate equation (A.1) with respect to a_2 and obtain

$$\frac{\partial^2 Cov(X_1,X_2)}{\partial a_2 \partial a_1} = \underbrace{\frac{\partial^2 \rho}{\partial a_2 \partial a_1}}_{?} \sqrt{Var(X_1)}\sqrt{Var(X_2)} + \frac{\partial \rho}{\partial a_1}\sqrt{Var(X_1)}\sqrt{Var(X_2)}\frac{1}{2}\frac{\frac{\partial(Var(X_2))}{\partial a_2}}{Var(X_2)}$$

$$+\frac{\partial Cov(X_1,X_2)}{\partial a_2}\frac{1}{2}\frac{\frac{\partial(Var(X_1))}{\partial a_1}}{Var(X_1)}$$

By Assumption 1, we have $\frac{\partial Cov(X_1,X_2)}{\partial a_2} \leq 0$. Assume also that $\frac{\partial \rho}{\partial a_1} < 0$. Moreover, $\frac{\partial^2 \rho}{\partial a_2 \partial a_1} = 0$ under linear parameterization of correlation coefficient, which is also adopted in Dasgupta and Maskin (1987). Furthermore, if it were the case that $p(a) \leq \frac{1}{2}$ for all $a \in [0,1]$ (as in Dasgupta and Maskin, 1987), then $\frac{\partial Var(X_1)}{\partial a_1} \leq 0$ and $\frac{\partial Var(X_2)}{\partial a_2} \leq 0$ from equation (A.2), which would imply that $\frac{\partial^2 Cov(X_1,X_2)}{\partial a_2 \partial a_1} > 0$, therefore $\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1} > 0$ from equation (A.10), whereby one could sign project choices as strategic substitutes. However, it may be the case that $p(a_i) > \frac{1}{2}$ for some $a_i \in [0,1]$ and $i \in \{1,2\}$, therefore, $\frac{\partial Var(X_1)}{\partial a_1} > 0$ and $\frac{\partial Var(X_2)}{\partial a_2} > 0$ at these points, which in turn implies that $\frac{\partial^2 Cov(X_1,X_2)}{\partial a_2 \partial a_1} < 0$. Then, in that case the net effect matters in signing $\frac{\partial^2 p_{SS}}{\partial a_2 \partial a_1}$ in equation (A.10).

A.3.2 On the proof of Lemma 1

In the following, we elaborate on the proof of Lemma 1. Let (a^c, a^c) be the unique Nash equilibrium to the firms' non cooperative game in the market. They are best responses to each other, therefore, satisfy F.O.C.s (equation (5))

$$\frac{\partial V_1(a^c,a^c)}{\partial a_1} = \phi_1(a^c,a^c;U_S,U_{SS}) = 0$$

$$\frac{\partial V_2(a^c,a^c)}{\partial a_2} = \phi_2(a^c,a^c;U_S,U_{SS}) = 0$$

Differentiate these conditions with respect to U_S and obtain

$$\begin{bmatrix} \frac{\partial a_1^c}{\partial U_S} \\ \frac{\partial a_2^c}{\partial U_S} \end{bmatrix} = -\begin{bmatrix} \frac{\partial^2 V_1}{\partial a_1^2} & \frac{\partial^2 V_1}{\partial a_1 \partial a_2} \\ \frac{\partial^2 V_2}{\partial a_2 \partial a_1} & \frac{\partial^2 V_2}{\partial a_2^2} \end{bmatrix}^{-1} \begin{bmatrix} \frac{\partial \phi_1}{\partial U_S} \\ \frac{\partial \phi_2}{\partial U_S} \end{bmatrix}$$

which leads to

$$\frac{\partial a_1^c}{\partial U_S} = -\frac{1}{\Delta}\left(\frac{\partial^2 V_2}{\partial a_2^2}\frac{\partial \phi_1}{\partial U_S} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2}\frac{\partial \phi_2}{\partial U_S}\right)$$

for firm 1 (the case for firm 2 is symmetric) where Δ is the determinant of the matrix of second-order derivatives of the objective functions of firms as defined in equation (A.4). From Corollary A.2, $\Delta > 0$ and the second order sufficient conditions hold for firms' problem in a market setting, therefore $\frac{\partial^2 V_1}{\partial a_1^2} < 0$ and $\frac{\partial^2 V_2}{\partial a_2^2} < 0$. Note that the sign of $\frac{\partial^2 V_1}{\partial a_1 \partial a_2}$, which determines the sign of the slope of best response function for firm 1 can go either way, that is, projects can be strategic complements or substitutes as discussed in the preceding section. One can also show that $\frac{\partial \phi_1^c}{\partial U_S} = \frac{\partial \phi_2^c}{\partial U_S}$ at symmetric points. Then,

$$\frac{\partial a_1^c}{\partial U_S} = -\frac{1}{\Delta}\underbrace{\left(\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2}\right)}_{?}\frac{\partial \phi_1}{\partial U_S} \tag{A.11}$$

at symmetric points. We sign the term $(\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2})$ as negative at the symmetric points as follows: Consider the case of strategic complements: that is $\frac{\partial^2 V_1}{\partial a_1 \partial a_2} > 0$. Then, $(\underbrace{\frac{\partial^2 V_2}{\partial a_2^2}}_{<0} - \underbrace{\frac{\partial^2 V_1}{\partial a_1 \partial a_2}}_{>0}) < 0$. Consider the case of strategic substitutes, that is, $\frac{\partial^2 V_1}{\partial a_1 \partial a_2} < 0$. Now, $\frac{\partial^2 V_1}{\partial a_1^2} = \frac{\partial^2 V_2}{\partial a_2^2}$ holds at symmetric points, then

$$\begin{aligned}\Delta &= \frac{\partial^2 V_1}{\partial a_1^2}\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2}\frac{\partial^2 V_2}{\partial a_2 \partial a_1} \\ &= \left[\frac{\partial^2 V_2}{\partial a_2^2}\right]^2 - \left[\frac{\partial^2 V_1}{\partial a_1 \partial a_2}\right]^2 \\ &= \left(\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial V_1}{\partial a_1 \partial a_2}\right)\left(\underbrace{\frac{\partial^2 V_2}{\partial a_2^2}}_{<0} + \underbrace{\frac{\partial^2 V_1}{\partial a_1 \partial a_2}}_{<0}\right)\end{aligned}$$

Because $\Delta > 0$, it implies that $(\frac{\partial^2 V_2}{\partial a_2^2} - \frac{\partial V_1}{\partial a_1 \partial a_2}) < 0$. Hence,

$$sign(\frac{\partial a^c}{\partial U_S}) = sign(\frac{\partial \phi_1}{\partial U_S})$$

Now, from equation (5.1),

$$\frac{\partial \phi_1}{\partial U_S} = \frac{\partial p_{SF}}{\partial a_1}$$

which is positive at the market solution (a^c, a^c) from the proof of Proposition 1. Moreover, equation (A.11) can be further arranged as

$$\frac{\partial a_1^c}{\partial U_S} = \left(\frac{1}{-(\frac{\partial^2 V_2}{\partial a_2^2} + \frac{\partial^2 V_1}{\partial a_1 \partial a_2})}\right)\frac{\partial p_{SF}}{\partial a_1}$$

Then, at symmetric market equilibrium, the resulting increase in project choice of firm 1 is higher if projects are strategic complements than the case that they are strategic substitutes as expected.

Similarly differentiating the F.O.Cs (equation (5.1) for firm 1) with respect to U_{SS} yields

$$\frac{\partial a_1^c}{\partial U_{SS}} = -\frac{1}{\Delta}\left(\frac{\partial^2 V_2}{\partial a_2^2}\frac{\partial \phi_1}{\partial U_{SS}} - \frac{\partial^2 V_1}{\partial a_1 \partial a_2}\frac{\partial \phi_2}{\partial U_{SS}}\right)$$

One can similarly establish that

$$sign(\frac{\partial a_1^c}{\partial U_{SS}}) = sign(\frac{\partial \phi_1}{\partial U_{SS}})$$

From equation (5.1)

$$\frac{\partial \phi_1}{\partial U_{SS}} = \frac{\partial p_{SS}}{\partial a_1}$$

which is negative everywhere in the domain, and at the symmetric market equilibrium, (a^c, a^c) , in particular. Finally, one can similarly verify that the resulting decrease in project choice of firm 1 is higher if projects are strategic complements than the strategic substitutes case as expected.

For the remaining claim in Lemma 1, because $U_S > 0$ arrange the payoff parameters in F.O.Cs (equation (5)) as

$$\frac{U_{SS}}{U_S}\frac{\partial prob(S,S)}{\partial a_1} + \frac{\partial prob(S,F)}{\partial a_1} = 0$$

$$\frac{U_{SS}}{U_S}\frac{\partial prob(S,S)}{\partial a_2} + \frac{\partial prob(F,S)}{\partial a_2} = 0$$

Having defined $R \equiv \frac{U_{SS}}{U_S}$, one can similarly establish that a^c is decreasing in R.

CHAPTER 3. ON THE "CO-EXISTENCE" BETWEEN GENETICALLY MODIFIED, CONVENTIONAL, AND ORGANIC PRODUCTS IN EUROPEAN AGRICULTURE: A MULTI-MARKET EQUILIBRIUM ANALYSIS[1]

Abstract

Although genetically modified (GM) crops have been quickly adopted in certain parts of the world, they have met with resistance from consumers in the European Union (EU) market. This has resulted in a complex (and ongoing) EU regulation, which envisions the co-existence of GM food with conventional and quality-enhanced products. As the regulation mandates the labeling and traceability of GM content in all stages of production and allows only a stringent adventitious presence of GM content in other products, it implies significant economic costs. Based on a partial equilibrium model of the EU agricultural food sector, we analyze the economic implications of introduction of GM food in the EU market. We develop, calibrate and simulate a model that captures the main features of the problem at hand. We find that the introduction of GM food is reducing overall welfare but the producers of quality-enhanced products become better off, a result that is robust to variations in the values of critical parameters.

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[1] This is a joint paper with GianCarlo Moschini and Luigi Cembalo.

1. Introduction

The advent of biotechnology in agriculture has resulted in momentous (and ongoing) adjustments in the agricultural and food sector. Over the course of only a few years, a large portion of the area cultivated to some basic commodities has been converted to planting of genetically modified (GM) crops. James (2003) reports that global planting of GM crops reached 67.7 million hectares in 2003, virtually all of which comprised four commodities: corn, soybean, cotton, and canola. The hallmark of these GM crops, relative to those deriving from prior breeding programs, is an exciting novel scientific approach: insertion of foreign genetic material that confers a specific attribute of great interest (such as herbicide or pest resistance). Somewhat paradoxically, the novelty of GM crops explains both the enthusiastic support of their proponents and the widespread consumer and public opposition that has hampered adoption in a number of countries. Indeed, as of now, GM crop adoption has been confined to a limited number of countries (the United States, Argentina, Canada, and China accounted for about 95% of total GM crop cultivation in 2003). Elsewhere, GM crop adoption has been slowed or hampered by novel regulation, apparently in response to the aforementioned vigorous public opposition (Sheldon, 2002).

Whereas some earlier studies have documented sizeable efficiency gains attributable to new GM crops (Falck-Zepeda, Traxler, and Nelson, 2000; Moschini, Lapan, and Sobolevsky, 2000), it has become clear that a major feature of this new technology deserves careful scrutiny from an economic perspective. Specifically, a possibly large share of consumers perceives food made from GM products as weakly inferior in quality relative to traditional food. But the mere introduction of GM crops means that, to deliver traditional GM-free food, additional costs must be incurred (relative to the pre-innovation situation). This is because the commodity-based production, marketing, and processing system, long relied upon by the food industry, is not suited to avoid the commingling of

GM and non-GM crops.[2] To satisfy the demand for non-GM food, costly identity preservation (IP) and segregation activities are required. Thus, the innovation process has, in this context, brought about a new market failure, essentially an externality on the production of traditional food products (Lapan and Moschini, 2004).

Nowhere has the public concern about GM products affected the regulatory process more than in the European Union (EU). An earlier laissez-faire approach, during which several GM products were approved, came to a halt in 1998 when the EU instituted a controversial *de facto* moratorium on new GM products. The extensive re-examination of the EU regulations pertaining to GM products that followed has produced a new framework meant to foster food safety, protect the environment, and ensure consumers' "right to know." The system is centered on the notions of labeling and traceability (Commission of the European Communities, 2003a). Specifically, the new EU regulations require that food and feed consisting of, or produced from, GM crops be clearly labeled as such and envision a system that guarantees full traceability of food products put on the marketplace. Mandatory labeling is to apply to food and feed produced from GM crops, including food from GM products even when it does not contain protein or DNA from the GM crop (e.g., beet sugar). The threshold for avoiding the GM label is quite stringent: only a 0.9% adventitious presence of (authorized) GM products in food is tolerated for a product marketed without a GM label.

Perhaps in recognition of the interdependence and externalities characterizing GM crop adoption, the EU is developing measures aimed at the "coexistence" between GM and non-GM agriculture (Commission of the European Communities, 2003b). The following extensive quote clarifies the EU position on this matter (European Union, 2003):

> *"The issue of co-existence refers to the ability of farmers to provide consumers with a choice between conventional, organic and GM products that comply with European labeling and purity standards. Co-existence is not about environmental or health risks because only GM crops that have been authorized as safe for the environment*

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[2] Indeed, contamination of traditional crops with undesired GM traits can arise before the farm gate, at the stage of seed production, and at the farm production stage, through cross-pollination with neighboring farms.

> *and for human health can be cultivated in the EU. Since different types of agricultural production are not naturally separated, suitable measures during cultivation, harvest, transport, storage and processing are needed in order to manage the possible accidental mixing (admixture) of GM and non-GM crops resulting from seed impurities, cross-pollination, volunteer and harvesting-storage practices. Co-existence is concerned with the potential economic loss through the admixture of GM and non-GM crops which could lower their value, with identifying workable management measures to minimize admixture and with the cost of these measures."*

Thus, the unintended economic implications of the introduction of GM crops are very much at the forefront here and motivate our study. Whereas the EU proposal contains fairly detailed suggestions on measures that are deemed necessary to ensure co-existence, the scale of the economic problem at hand has not, to date, been analyzed in a coherent economic model. Indeed, current analysis on the economic impacts of GM product adoption have either assumed that GM and non-GM products are equivalent (Falck-Zepeda, Traxler, and Nelson, 2000; Moschini, Lapan, and Sobolevsky, 2000; Demont and Tollens, 2004; Demont, Wesseler, and Tollens, 2004) or that there are two qualitatively different products—one GM and one non-GM—such that non-GM products are treated as one type of good (Desquilbet and Bullock, 2001; Fulton and Giannakas, 2004; Lapan and Moschini, 2004).

The latter approach does reveal some important insights into the economics of GM crop adoption, including the finding that the GM innovation, in the end, may not improve welfare. But existing models are not refined enough to assess the differential impact that GM adoption may have when pre-existing products are already differentiated. In particular, the co-existence issue detailed earlier explicitly indicates the need to allow for three distinct products (conventional, organic and GM). Furthermore, while it has been shown that the welfare impact of GM innovation is ambiguous, it is unclear what market conditions are required to produce negative as opposed to positive welfare effects. In the context of a larger model that tries to accommodate the three types of products singled out by the co-existence issue, such welfare effects are likely to depend on the interdependence between markets. More specific attention to such multi-market effects appear warranted.

In this paper we develop a modeling framework that extends previous work by considering the introduction of GM products in a system where two differentiated products already exist: "conventional" food and "quality-enhanced" food. In the empirical part of the paper, the latter is identified with "organic" food, although more generally it is intended to refer to a broader set of products that Europeans claim as a distinguishing feature of their agriculture (Fishler, 2002). The notion of "organic food" refers to the products of regulated production processes that essentially forego the use of a range of chemical inputs (fertilizers, herbicides, and pesticides) that are widely used in conventional agriculture. What specifically can be called "organic" is a matter of national regulations, and the EU has its own rules and standards.[3] More than 24 million hectares worldwide are currently cultivated with practices that can claim to be organic (Willer and Yussefi, 2004). In the EU, organic production accounts for about 3% of the utilized agricultural area (UAA). But the EU recognizes that a large number of other food products can claim superior quality attributes. The identification of these products in the marketplace is promoted by EU regulations that established special labels known as PDO (Protected Designation of Origin), PGI (Protected Geographical Indication) and TSG (Traditional Speciality Guaranteed).[4]

A first contribution of the paper is to derive a model of differentiated food demand that is consistent with the stylized attribute of the problem at hand. Specifically, we derive a demand system that admits three food products: conventional food, organic food, and GM food (in addition to a *numéraire* good). The GM good is a weakly inferior substitute for the conventional food, and the model is specified in such a fashion that all of the relevant parameters can be identified from observation of the pre-innovation equilibrium. The supply side similarly accounts explicitly for the production of two and three products (before and after the GM innovation, respectively). For the

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[3] See the EU Web page on "Organic Agriculture" at: http://europa.eu.int/comm/agriculture/qual/organic/.

[4] At present there are more than 600 food products in the EU that can claim such "quality" labels, although their importance in terms of market share (and ultimately in terms of land used in their production) is not known. See the EU Web page on "Quality Policy" at: http://europa.eu.int/comm/agriculture/foodqual/quali1_en.htm.

"quality" agricultural product, the quality enhancement is modeled as deriving from additional efforts supplied by producers. Equilibrium conditions account explicitly for the IP costs that are necessary after the introduction of GM products and endogenize the price of land as well as the reward to the additional efforts supplied by farmers. The model is calibrated to replicate observed data of EU agriculture, based on assumed values of some critical parameters. The solution of the model—for baseline parameter values as well as other alternatives—allows us to determine the qualitative and quantitative economic impacts of the adoption of GM crops in the EU.

2. Modeling strategy

We seek a model that strikes a balance between the competing needs of details and simplicity—the former allowing us to represent the problem of interest with some accuracy; the latter providing the necessary modeling abstraction for some unambiguous results to emerge. Because we are dealing with at least three products, it is not possible to derive unambiguous results for the market and welfare effects of GM innovation under general demand and supply conditions. In addition to the ambiguities that may result from unrestricted demand substitution possibilities,[5] the innovation that we are modeling entails a market failure, as discussed in the introduction. Thus, the post-innovation equilibrium is bound to represent a second-best situation—for example, both an increase and a decrease of aggregate welfare are possible. Standard comparative statics analysis is bound to produce inconclusive results. To proceed, the strategy that we adopt is to restrict the specification of both demand and supply relations to capture some stylized facts of GM product innovation. Having done that, we calibrate the model such that the chosen parameters are consistent with generally accepted attributes of the agricultural sector and can replicate exactly the benchmark data set. By solving the

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[5] Even in a simpler two-product case, Lapan and Moschini (2004) show that some additional restrictions on demand, over and above the properties that result from standard utility maximization, are required.

model thus calibrated under various assumptions, we can then shed some light on both the qualitative and quantitative potential effects of large-scale GM product adoption on European agriculture.

A major issue in the GM policy debate concerns consumers' attitudes toward these new products. In representing the demand side of the market, therefore, we allow for the fact that the three food products are perceived as differentiated by consumers. But we also want to capture some stylized facts about consumer preferences with respect to these goods. Specifically, conventional food is deemed no worse than GM food—in the definition of Lapan and Moschini (2004), GM food is a "weakly inferior" substitute for conventional food. It seems that individual preferences are also quite heterogeneous with respect to our other product, organic food. But whereas some consumers have a strong preference for organic food, often based on perceived health, environmental, and animal-welfare considerations, other consumers may, *ceteris paribus*, prefer conventional food based on other quality attributes (such as appearance, integrity, and taste). Thus, in particular, the assumption that convention food is "weakly inferior" to organic food would seem untenable. Hence, we develop a demand framework whereby organic and conventional food products are "horizontally differentiated" whereas GM and non-GM food products are "vertically differentiated." We submit that this novel approach, detailed in the section to follow, captures in an effective way the main attributes of demand in our context.

As for the supply side, an essential facet of the "co-existence" issue relates to the adjustments in production brought about by the innovation adoption, in particular with regard to the welfare of farmers. Concerning the latter, in a purely competitive sector such as agriculture, returns to producers must be associated with the presence of some fixed factors of production. Land being the obvious such fixed factor, in our model we represent the entire agricultural sector and assume that there is a given endowment of land that can be used to produce two outputs before GM innovation (conventional and organic products) and that there are three outputs after GM innovation (conventional, organic, and GM products). Furthermore, it is apparent that organic products command a sizeable price premium over conventional ones, while organic production only accounts for a small share of overall production. The modeling avenue that we postulate to account for such stylized facts is that organic production requires an additional input in the form of farmer-supplied effort, and that this required extra labor input has an upward-sloping supply. This is certainly consistent with the observation that organic production is typically more labor intensive, with customized labor tasks substituting for inadmissible chemical inputs. Because this modeling strategy effectively suffices in discriminating conventional and organic production, we then proceed by assuming that land quality is homogeneous.[6]

Moving to equilibrium considerations, a critical need in this setting is to represent the novel impacts of GM product introduction in the marketplace. As discussed in the introduction, this requires an explicit consideration of the costs of identity preservation activities that are required, after innovation adoption, to supply non-GM products to the consumers who want them. Furthermore, as discussed by Lapan and Moschini (2004), it may be of interest to distinguish between the cost of identity preservation itself with the additional burden that may be imposed by specific product labeling rules. Whereas food labeling in general serves the ultimate purpose of conveying useful information to consumers (Golan et al., 2000), mandating that the inferior product carry the "GM label," as required by the recently approved EU rules, appears to do little in that regard. In particular, requiring GM products to identify themselves via a label does not alleviate the cost of identity preservation (to be borne by non-GM suppliers) that is necessary to provide consumers with (credible) non-GM food. Put another way, from an information economics point of view it is the "superior" (i.e., non-GM) product that should carry the label. Thus, in our model we try to distinguish between the effects of identity preservation (of the superior products) and the impact of labeling and traceability requirements (on the inferior product).

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[6] Admittedly this is a simplification. But we would argue that the alternative of also allowing for a heterogeneous land endowment would add little additional economic insight while adding considerable burden to the model.

A final consideration about our model is worth noting. The model that we develop and solve is calibrated at the farm-gate level. Accordingly, the demand functions that we consider must be interpreted as "derived demands." In addition to reflecting the nature of final EU consumer demand, such derived demands implicitly account for the (net) excess demand for EU products originating from the export market. Thus, although the model is isomorphic to the representation of a close economy sector, it is in fact consistent with an open economy setting.

3. The model

Based on the foregoing, the demand, supply and equilibrium conditions of an agricultural and food sector before and after GM innovation are specified as follows.

3.1. Demand

Because it is widely accepted that such features of food demand arise from a collection of consumers that manifest widely differing attitudes towards organic and GM food, it is useful to derive aggregate demand explicitly from the specification of individual consumer preferences. To implement the notion of "weakly inferior" substitutes, we extend the vertical product differentiation model with unit demand of Mussa and Rosen (1978) (see also Tirole, 1988, chapter 7). In that setting, one postulates a population of consumers with heterogeneous preferences concerning two goods (in addition to the *numéraire*) but in which all consumers agree that one good is no worse than the other, *ceteris paribus*. We generalize that framework by allowing one additional good, such that the individual agent utility function is defined over four goods: conventional food q_n, organic food q_b, GM food q_g, and a composite good y (the *numéraire*).[7] Furthermore, consumers here are not restricted to buy one unit of the product but decide how much to purchase (in addition to which good to purchase). As in the

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[7] The subscript *n* stands for "normal," the subscript *b* stands for "biologic" (the attribute for "organic" in many European languages), and the subscript *g* stands for "genetically" modified.

standard vertical product differentiation model, preferences are assumed to be quasi-linear, such that the individual consumer's utility function is written with the following structure:

$$U\left(y, q_b, q_n, q_g \middle| \theta\right) = y + u\left((q_n + \theta q_g), q_b\right) \tag{1}$$

where the function $u(.)$ is assumed to be concave, and θ is an individual parameter that characterizes the heterogeneity of consumers vis-à-vis their preference for GM food relative to conventional food.

Note that, absent GM food, the utility function (apart from the *numéraire*) reduces to $u\left(q_n, q_b\right)$. Thus, conventional and organic foods are treated as imperfect substitutes, but with no presumption that one is uniformly better than the other for all consumers. On the other hand, to capture the fact that GM food is assumed to be a weakly inferior substitute for the conventional food, we assume that the distribution of the corresponding parameter satisfies $\theta \in [0,1]$. In the foregoing specification, each individual consumer will consume two goods: either organic and conventional, or organic and GM, although the heterogeneity of consumers implies that, in aggregate, all three food types may be consumed.[8]

More specifically, the consumer will buy the GM good if and only if $p_g \leq \theta p_n$, whereas he or she would buy the conventional food if $p_g > \theta p_n$.[9] So, let $Q \equiv q_n + \theta q_g$ and let $p_Q \in \left\{p_n, p_g/\theta\right\}$ denote the price of Q that applies (depending on whether q_n or q_g is consumed). Now consider the problem of choosing Q and q_b with the utility function rewritten as $U = y + u\left(Q, q_b\right)$. Then the optimality conditions for an interior solution are $u_Q(Q, q_b) = p_Q$ and $u_{q_b}(Q, q_b) = p_b$, which yield the individual demand functions $d_Q(p_Q, p_b)$ and $d_b(p_Q, p_b)$.

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[8] We assume that $u(q)$ is such that the consumer will buy some amount of one of the goods, and that income is sufficiently high so that an interior solution holds.

[9] The consumer is indifferent between the two varieties if the equality holds, but we will make the conventional assumption that, under equality, the GM food is purchased.

As for the choice between q_n and q_g, as discussed earlier, that will depend on how the price ratio p_g/p_n relates to θ. Let $G \equiv \{\theta \in [0,1] \mid \theta \geq p_g/p_n\}$ denote the set of individuals that, at given prices, will prefer the GM product (this set is empty if $p_g > p_n$), and let $N \equiv \{\theta \in [0,1] \mid \theta < p_g/p_n\}$ denote the set of individuals that, at given prices, will prefer the conventional product. Then individuals of type $\theta \in N$ will buy

$$q_n = d_Q(p_n, p_b), \qquad q_b = d_b(p_n, p_b), \qquad \text{and} \qquad q_g = 0 \tag{2}$$

whereas those of type $\theta \in G$ will buy

$$q_n = 0 \ , \qquad q_b = d_b\left(p_g/\theta, p_b\right), \qquad \text{and} \qquad q_g = \frac{1}{\theta} d_Q\left(p_g/\theta, p_b\right) \tag{3}$$

Market demand functions are obtained by integrating over all types. Thus,

$$D_n\left(p_n, p_g, p_b\right) = \int_{\theta \in N} d_Q(p_n, p_b) dF(\theta) \tag{4}$$

$$D_g\left(p_n, p_g, p_b\right) = \int_{\theta \in G} \frac{1}{\theta} d_Q\left(p_g/\theta, p_b\right) dF(\theta) \tag{5}$$

$$D_b\left(p_n, p_g, p_b\right) = \int_{\theta \in N} d_b(p_n, p_b) dF(\theta) + \int_{\theta \in G} d_b\left(p_g/\theta, p_b\right) dF(\theta) \tag{6}$$

where $F(\theta)$ denotes the distribution function of consumer types.[10]

To find an explicit representation of demand functions, we parameterize the utility function as follows:

$$u(Q, q_b) = \left(\frac{\varepsilon}{\varepsilon - 1}\right)(k)^{\frac{1}{\varepsilon}} \left[Q^{\lambda} (q_b)^{1-\lambda}\right]^{\frac{\varepsilon-1}{\varepsilon}} \tag{7}$$

where the parameter $\lambda \in (0,1)$ controls the share between conventional and organic food, the parameter $\varepsilon > 0 \quad (\varepsilon \neq 1)$ controls the overall food demand elasticity, and the parameter $k > 0$

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[10] Note that this formulation is general enough to accommodate continuous, discrete, and mixed distributions of consumer types.

controls the size of the market. Given this utility function, it is easily verified that the individual demand functions display constant elasticity, specifically,

$$d_Q(p_Q,p_b)=K\cdot\left(p_Q\right)^{-1+\lambda(1-\varepsilon)}\left(p_b\right)^{(1-\varepsilon)(1-\lambda)} \tag{8}$$

$$d_b(p_Q,p_b)=K\cdot\left(p_Q\right)^{\lambda(1-\varepsilon)}\left(p_b\right)^{-\varepsilon-\lambda(1-\varepsilon)} \tag{9}$$

where $K\equiv k(\lambda)^{1-\lambda(1-\varepsilon)}(1-\lambda)^{-(1-\varepsilon)(1-\lambda)}$.

Finally, to get closed-form solutions for the market demand function we need to make assumptions about the distribution of consumer types (i.e., the parameter θ). To this end, we wish to allow for a fraction of consumers to be "indifferent" between conventional and GM products. Given the choice, such consumers would simply buy the less costly of the two goods. Thus we specify a mixed distribution function $F(\theta)$ such that for a fraction $\phi\in(0,1)$ of consumers the type is $\theta=1$, whereas for the remaining consumers the type θ is uniformly distributed on $[0,1)$.[11] Hence, the density $f(\theta)\equiv F'(\theta)$ on $[0,1)$ is $f(\theta)=1-\phi$.

Given that, evaluating the integrals in equations (4)-(6), given the individual demands in equations (8)-(9), for the case $p_n\geq p_g$ we obtain

$$D_n\left(p_n,p_g,p_b\right)=d_Q(p_n,p_b)(1-\phi)\left(\frac{p_g}{p_n}\right) \tag{10}$$

$$D_g\left(p_n,p_g,p_b\right)=d_Q\left(p_g,p_b\right)\left[\phi+A\left(p_n,p_g\right)\right] \tag{11}$$

$$D_b\left(p_n,p_g,p_b\right)=d_b(p_n,p_b)(1-\phi)\left(\frac{p_g}{p_n}\right)+d_b\left(p_g,p_b\right)\left[(1-\phi)A\left(p_n,p_g\right)+\phi\right] \tag{12}$$

where $d_Q(\cdot,p_b)$ and $d_b(\cdot,p_b)$ are given by (8) and (9), and

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[11] As suggested by a reviewer, the parameter ϕ may also capture stylized facts about consumers' handling of label information (Noussair, Robin, and Ruffieux, 2002). One could also postulate the existence of a fraction of consumers for which $\theta=0$. But, as observed by this reviewer, imperfect information uptake from labels would spread this group, justifying the continuous distribution that we have postulated on $[0,1)$.

$$A\left(p_n, p_g\right) \equiv \frac{(1-\phi)}{\left(1-\lambda(1-\varepsilon)\right)}\left(1-\left(\frac{p_g}{p_n}\right)^{(1-\lambda(1-\varepsilon))}\right) \tag{13}$$

For the case $p_n < p_g$, as noted earlier, $D_g(p_b, p_n, p_g) = 0$. Such a case describes the situation prior to the introduction of GM food, where $D_g = 0$ and the demands for conventional and organic food reduce to

$$D_n\left(p_n, p_g, p_b\right) = d_Q(p_n, p_b) \tag{14}$$

$$D_b\left(p_n, p_g, p_b\right) = d_b(p_n, p_b) \tag{15}$$

where, again, the functions $d_Q(\cdot, p_b)$ and $d_b(\cdot, p_b)$ are as defined in (8) and (9). Note that the demand structure for the new product is described in terms of the same underlying preference parameters $\left(k, \varepsilon, \text{ and } \lambda\right)$, a feature that is particularly convenient at the calibration and simulation stage.

3.2. Production and supply

To capture the essential elements of the "co-existence" issue for the supply side, as discussed earlier, we model the entire agricultural sector and assume that there is a given endowment of land that can be used to produce two outputs before GM innovation (conventional and organic products) and three outputs after GM innovation (conventional, organic, and GM products). To keep things as simple and transparent as possible for the purpose of calibration, and yet obtain non-trivial outcomes at the policy analysis stage, we assume constant returns to scale (at the industry level) for both conventional and GM production. Specifically, if x_n denotes production of conventional food, π is the unit rental price of land, and w is the vector of prices of the intermediate inputs used in food production, the cost function can be written as

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$$C^n(x_n, w, \pi) = x_n\left[\alpha_n \pi + c^n(w)\right] \qquad (16)$$

where α_n is a parameter that can be interpreted as the reciprocal of yield, and $c^n(w)$ is an increasing, linearly homogeneous, and concave function of prices. Note that this cost function is dual to a production function with a fixed proportion between land and a function of the bundle of market inputs (unrestricted substitutability between market inputs is thus allowed).

Production of organic food, on the other hand, is assumed to require three types of inputs: land, market-supplied inputs, and farmer-supplied effort. Again we assume fixed proportions between land, a function of the bundle of market supply inputs, and farmer-supplied effort measured in some efficiency units. But for the latter we assume that the cost of drawing the required farmer-supplied efforts into organic production are increasing at the margin. For instance, one can imagine a population of potential organic farmers, each with its own reservation price to enter this particular industry (the heterogeneity displaying different abilities for supplying the effort required in organic food production). If x_b denotes the production of organic food,

$$C^b(x_b, w, \pi) = x_b\left[\alpha_b \pi + c^b(w, z)\right] \qquad (17)$$

where α_b is the parameter representing the reciprocal of yield, z is a variable that indexes farmer-supplied inputs used in organic food production, and $c^b(w, z)$ is increasing, linearly homogeneous, and concave in w, and increasing in z (more on this to follow).

We measure conventional food and organic food in the same units. Typically, the presumption is that production per unit of land (i.e., yield) is lower in organic food production, which would imply $\alpha_b > \alpha_n$. Furthermore, we assume that the price vector w of the intermediate inputs is given, and thus we subsume its effect in the unit sub-costs. Specifically, for the conventional product we write $c^n(w) \equiv c$ such that (for given π and w) conventional food production is a constant marginal cost industry. Organic production, on the other hand, is assumed to be an increasing cost industry: at the margin, expanding organic production requires additional farmer-supplied inputs that are available only at increasing cost. To capture that, and still take all market prices as given, we write $c^b(w,z) \equiv c \cdot (1+\rho z)$, where $\rho > 0$ is a parameter to be determined at the calibration stage. More specifically, we normalize $z \in [0,1]$ (without loss of generality, because units are arbitrary) so that we can interpret z as the fraction of land that is allocated to organic production. Given this, before the advent of GM products the marginal costs of production are written as, respectively, $MC_n = c + \alpha_n \pi$ and $MC_b = c \cdot (1+\rho z) + \alpha_b \pi$.

With the introduction of GM products, GM food production x_g becomes feasible. Given the standard effects of first-generation GM agricultural products, which constitute almost the totality of GM crops being grown at present (James, 2003), we assume that the main attribute of GM crops is to provide higher production efficiency at the farm level. We model that by postulating that the GM technology cuts the cost of the bundle of market-supplied inputs,[12] such that the unit cost of market-supplied inputs for GM crop production is γc, where $0 < \gamma < 1$. But GM products also impose the need for IP, which we model by postulating a unit segregation cost s_n on the production of conventional food, and a unit segregation cost s_b on the production of organic food.[13]

Furthermore, GM regulation may mandate an additional unit cost t for the producers of GM food (i.e., the traceability and mandatory labeling requirements envisioned by the EU). Thus, the introduction of GM products affects the production costs of all three food products, and the post-innovation marginal production costs are represented by

$$MC_n = c + \alpha_n \pi + s_n \tag{18}$$

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[12] This implicitly accounts for the fact that some input prices (e.g., improved seeds) may actually change with the introduction of GM technology.

$$MC_b = c \cdot (1 + \rho z) + \alpha_b \pi + s_b \tag{19}$$

$$MC_g = \gamma c + \alpha_n \pi + t \tag{20}$$

3.3. Equilibrium

Based on the foregoing, and given a fixed amount of land L, the (partial) competitive equilibrium in the agricultural sector after the GM innovation (assuming that all three products are produced) can be written as

$$p_n^* = c + \alpha_n \pi^* + s_n \tag{21}$$

$$p_b^* = c \cdot (1 + \rho z^*) + \alpha_b \pi^* + s_b \tag{22}$$

$$p_g^* = \gamma c + \alpha_n \pi^* + t \tag{23}$$

$$D^b(p_b^*, p_n^*, p_g^*) = x_b^* \tag{24}$$

$$D^n(p_b^*, p_n^*, p_g^*) = x_n^* \tag{25}$$

$$D^g(p_b^*, p_n^*, p_g^*) = x_g^* \tag{26}$$

$$z^* L = \alpha_b x_b^* \tag{27}$$

$$L = \alpha_b x_b^* + \alpha_n x_n^* + \alpha_n x_g^* \tag{28}$$

which can be solved for the post-innovation equilibrium values $(x_b^*, x_n^*, x_g^*, p_b^*, p_n^*, p_g^*, z^*, \pi^*)$. The pre-innovation equilibrium is a special case, obtained by dropping equations (23) and (26), by setting $s_n = s_b = t = 0$, and by constraining the price of the new product to $\bar{p}_g$ (the "choke" price, that is, the

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[13] The parameter s_b will also capture the policies of organic food classification vis-à-vis the presence of trace amount of GM food. For example, the requirement of zero-tolerance of GM product in the US and EU organic food classification can be interpreted as increasing the value of s_b.

price that would drive GM food demand to zero). The resulting conditions can then be solved for the pre-innovation equilibrium values $(x_b^*, x_n^*, p_b^*, p_n^*, z^*, \pi^*)$.

4. Data and calibration

We present the data on the parameters of the model in Table 1, which refers to the year 2000. Data for the total EU utilized agricultural area (UAA) are obtained from the EU Directorate General for Agriculture (2003). The land utilized by the quality products (mostly represented by organic food), which is denoted by L_b, amounts to 2.9% of the total EU UAA (Hamm, Gronefeld, and Halpin, 2002). The rest of the total EU UAA is assumed to be allocated to normal food production, which is denoted by L_n. The value of total agricultural production is obtained from the report of the EU Directorate General for Agriculture (2003). The value of quality food production is calculated based on data reported by Hamm, Gronefeld, and Halpin (2002).[14] The difference between the values of total and the organic food production is accounted as the value of conventional food production. The price of conventional food is normalized to 1, so that the amount of conventional food production is the value of conventional food production. The yield for the conventional product is then calculated by dividing the estimated production in volume by the estimated land used for the conventional product.

The price index for organic products that we have computed displays the price "premium" of such products over the conventional ones (the price of which was normalized to 1). Using this premium, the amount of organic food production is obtained by dividing the value of organic food with its price index. The yield for organic food production is calculated by dividing the amount of organic food production by the amount of land used in that industry. Using the data on average rent per hectare and the amount of agricultural land for each country in the EU (EU Directorate General

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[14] Details are reported in the Appendix section.

for Agriculture, 2003), the rent attributable to total utilized land was calculated to be 11% of the total value of agriculture in the EU. The value of π (unit rent) is then obtained by dividing total rent by the total amount of land. Then, the average production cost for conventional food (c) was calculated as the difference between the price of conventional food and rent expense per unit of conventional food, as formulated in equation (21) (with $s_n = 0$).

The economics of identity preservation and segregation for different commodities and markets have been studied in recent years, and some preliminary estimates of likely segregation costs are available. In particular, the study by the European Commission (2002) analyzing possible scenarios for the co-existence of GM, conventional, and organic crops in the EU, estimated segregation costs for commodities. Expressing such costs as the percentage of corresponding commodity prices, IP costs were estimated in the ranges of 4.5% and 9.5% for maize and 1.4% and 3.2% for potatoes (to meet a 1% threshold level). Moreover, Desquilbet and Bullock (2001) considered the segregation costs at the farm and handling stages to be 4% of the price the farmer gets and 20% of the handler's mark-up at maximum. Sobolevsky, Moschini, and Lapan (2004), following Lin, Chambers, and Harwood (2000), relied on a range of segregation costs between 3.4% and 10.3% of the average US producers' price for soybean.

Based on the foregoing, in this study we took the segregation cost to be 5% of the selling price in the baseline solution. Therefore, using the pre-innovation price of conventional food in the market, which is normalized to equal 1, the segregation costs s_n and s_b for conventional and quality food products, respectively, are set to 0.05 euros per unit in the baseline scenario.

For eight midwestern states, Bullock and Nitsi (2001) estimated that the introduction of glyphosate-resistent soybean technology, which is also known as Roundup Ready (RR) soybean technology, reduced the variable cost of production on average by 6.34% per conventional-till acre (and per bushel as yield was assumed to be the same for both RR and conventional technologies) and by 8.57% per no-till acre. These estimates included the decrease in production cost of non-RR technology due to the decrease in price of non-glyphosate herbicides after the introduction of RR technology. Sobolevsky, Moschini, and Lapan (2004) estimated the cost reduction obtained by using RR soybean technology in Iowa to be between 1.4% and 3.4%, depending on the herbicide treatment. Note that both studies took into account the price premium paid to GM seeds. We assumed that the average cost of conventional production remains the same with the introduction of GM technology and assumed that the reduction in average cost obtained by producing GM food (net of GM seed markup) is equal to 2%. Therefore, $\gamma = 0.98$.

Labeling and traceability costs are implemented in the model by the parameter t. In the baseline solution we assume $t = 0$ but consider the effects of these costs by solving the model with alternative values of this parameter.

Finally, the parameter representing the percentage of consumers who are indifferent between GM and conventional food versions (when the two varieties are offered at the same price) is taken to be $\phi = 0.25$ based on the representative surveys of European consumers (Moon and Balasubramanian, 2001, and Noussair, Robin, and Ruffieux, 2002). As noted earlier, without loss of generality we assume that those indifferent consumers will purchase GM food (any other allocation of indifferent consumers could be implemented by changing the value of ϕ).

Given the above, what remains is to calibrate the demand parameters ($\varepsilon > 0$, $\kappa > 0$, $\lambda > 0$) and the production parameter $\rho > 0$. We do so by ensuring that, given the other assumptions detailed in the foregoing, the chosen parameters make certain that the model predicts the observed prices and quantities for the benchmark year 2000. The value of the production parameter can be solved from equation (22) in the pre-innovation competitive equilibrium ($s_b = 0$) by using the data presented in Table 1, as follows. First, given the unit rent $\pi = 208.8$ computed as described earlier, from equation (21) (with $s_n = 0$) the production cost parameter c must satisfy $(p_n - c)/\alpha_n = 208.8$. Next, given

$\pi = 208.8$ and $z = 0.029$ (obtained as the fraction of land allocated to organic production), from equation (22) of the pre-innovation equilibrium we solve for $\rho = 10.653$.

To calibrate the demand parameters involves making assumptions about the parameters ($\kappa, \varepsilon, \lambda$) such that the benchmark prices and quantities are replicated, in addition to satisfying likely values of the demand elasticities involved. A possible difficulty in this context is that the parameters govern not only the own-price elasticities but also the cross-price elasticities (including elasticities of demand for GM food, a product that was not yet on the market in the benchmark year.) But our specification is particularly useful here, because we can deduce the behavior of the demand system from the value of a "total elasticity" that refers to aggregate food demand. To see this, define total demand as

$$D^T(p_b, p_n, p_g) \equiv D^b(p_b, p_n, p_g) + D^n(p_b, p_n, p_g) + D^g(p_b, p_n, p_g) \qquad (29)$$

Given this, we define the total demand elasticity as

$$\eta_T = \left. \frac{\partial D^T(\tau p_b, \tau p_n, \tau p_g)}{\partial \tau} \frac{\tau}{D^T(\tau p_b, \tau p_n, \tau p_g)} \right|_{\tau=1} \qquad (30)$$

It can be verified that in our demand structure we have $\eta_T = -\varepsilon$. Thus, the parameter ε is a measure of the elasticity of total food demand, which is known to be quite inelastic in developed countries (Tiffin and Tiffin, 1999; Moschini, 1998; Gracia, Gil, and Angulo, 1998). But here we also need to consider that in our model the demand is for EU-produced food (i.e., net of import and exports), and thus it is likely more elastic than the final EU demand for food. Given this likelihood, in the baseline solution we assume $\varepsilon = 0.4$. Conditional on these elasticity values, the market clearing conditions in equations (24)-(25) (with the price of GM product set to the choke level $\bar{p}_g$) are solved for the remaining two demand parameters, by using the demand functions from equations (14) and (15), to yield $k =$ 238.7 (billion) and $\lambda = 0.989$.

5. Results

Given our calibration procedure, solving the model for the pre-innovation equilibrium replicates observed price and quantity levels for the year 2000. Solving the model for the post-innovation equilibrium allows us to trace the main economic implications of the adoption of GM products in a setting characterized by differentiated consumer demand and the need for a segregation cost arising from the "externality" brought about by the introduction of the new GM crops. The economic effects that we focus on relate to the direction of price changes for traditional, organic, and GM products and the distribution of welfare effects across agents (consumers and producers). Specifically, in our model there are three welfare effects of interest. First, consumers are affected by the innovation, and thus we wish to compute the change in aggregate consumer surplus, ΔCS. Agricultural producers' welfare is also affected by the innovation. In particular, our model admits two distinct components of what is usually referred to as "producers' surplus" change, ΔPS: a change in the return to land and a change in the return to efforts for producers of organic product.

Consider first consumer welfare. Denote the pre-innovation and post-innovation equilibrium solutions with superscripts $i=0$ and $i=1$, respectively, such that the pre- and post-equilibrium prices are written as (p_n^0, p_b^0, p_g^0) and (p_n^1, p_b^1, p_g^1). It follows that the change in total consumers' surplus is

$$\Delta CS = -\int_{p_b^0}^{p_b^1} D_b(p_b, p_n^0, p_g^0)dp_b - \int_{p_n^0}^{p_n^1} D_n(p_b^1, p_n, p_g^0)dp_n - \int_{p_g^0}^{p_g^1} D_g(p_b^1; p_n^1, p_g)dp_g \qquad (31)$$

As for producers' surplus, as mentioned earlier, our model admits two distinct components. Consider the return to efforts for organic food producers, labeled as R_b^i, $i \in \{0,1\}$. Then in our model these returns satisfy

$$R_b^i \equiv \frac{L}{\alpha_b} \int_0^{z^i} [p_b^i - MC_b^i(z)]dz \qquad (32)$$

where $MC_b^i(z) = c \cdot (1 + \rho z^i) + \alpha_b \pi^i + s_b^i$. Performing the integration obtains

$$R_b^i = \frac{(z^i)^2 L \rho c}{2\alpha_b} \tag{33}$$

The other component of producers' surplus is the return to landowners at equilibria $i \in \{0,1\}$, which satisfies $V_L^i = \pi^i L$. Hence, the change in surplus accruing to landowners is $\Delta V_L = (\pi^1 - \pi^0)L$ and the change in surplus accruing to organic food producers is $\Delta R_b = R_b^1 - R_b^0$, such that the total change in producer surplus is $\Delta PS = \Delta R_b + \Delta V_L$. Finally, total welfare change arising from the innovation is measured as $\Delta W = \Delta CS + \Delta PS$.

5.1. Baseline scenario

In the base scenario the model was solved with the calibrated parameters reported in Table 1. Note that the cost for labeling and traceability of GM food (over and above the cost of IP) here is set equal to zero (i.e., $t = 0$). Although there are likely minimal costs involved in labeling GM food *per se*, the record-keeping mandated by the traceability requirements on GM food are likely more onerous. Still, the benchmark of zero labeling and traceability costs is of some interest, especially if one wants to disentangle the effects of such activities from the actual segregation costs necessary to supply consumers with what they perceive as the superior products (conventional and organic food with IP), and therefore we begin our analysis with that assumption. We shall perform sensitivity analysis regarding this parameter value later. The other critical parameter is the segregation cost. In the baseline scenario we assume that conventional food and organic food face the same segregation costs, following the introduction of GM products, and thus (as per earlier discussion) we set $s_n = s_b = 0.05$.

Results for the base scenario are reported in Table 2. With the introduction of GM food, the price of GM food declines relative to the pre-innovation choke price (recall that there is no demand for GM food for all $p_g > p_n$), and this new product displaces mainly the conventional product (conventional food production decreases by 30.7 % and GM food production accounts for 30.4% of total output in the new equilibrium). To interpret these and subsequent results it helps to note explicitly that the difference in equilibrium prices between conventional and GM products is determined by the supply side of the model, specifically $p_n^* - p_g^* = (1-\gamma)c + s_n - t$. Given this price difference, in turn, the demand side determines the relative share of GM and non-GM products on the market. Absent segregation costs, the introduction of a more efficient production (the GM product) would tend to increase the returns to land (the unit rent π). But the existence of segregation costs puts a wedge between the demand prices and supply prices for the conventional and organic products and leads to a sizeable erosion to the returns to land (the fixed factor). At the demand level, the price of GM food of course decreases relative to the pre-innovation choke price level. The price of organic food decreases at the demand level (despite the need for segregation) because the production-cost impact of the decline in the rental price of land is much more important for this (land-extensive) sector. The price of conventional food, on the other hand, increases at the demand level (because the effect of segregation costs, which act like a tax, dominates).

All producer prices decrease in the new equilibrium (which in turn accounts for why the unit rent value of land decreases). As for welfare effects, returns to land of course decline, but the non-land returns to organic food producers increase. Overall, however, the returns to land obviously dominate, and producer surplus declines substantially. Consumer surplus also declines: given our parameterized preferences, the decline in the price of GM and organic food is not enough to compensate for the increase in conventional food price. Because both producers and consumers lose in the aggregate, the introduction of GM food in the EU agro-food system unambiguously decreases the total welfare by 7.7%. We should emphasize again that, unlike other studies in this area, in our calculation we do not account for the *ex post* returns to innovators that develop the GM crops.[15]

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[15] One way to rationalize our procedure is to consider *ex post* returns to innovators as compensating, in expectation, for the R&D investments that made the innovation possible. An alternative argument for ignoring the potential returns to the R&D sector is presented in Demont, Wesseler, and Tollens (2004).

To further illustrate and qualify the foregoing results of the baseline scenarios, in what follows we carry out a sensitivity analysis, whereby the effects of changes in the value of some key parameters are explored.

5.2. Effects of segregation cost for organic food

In the baseline solution we postulated that segregation costs for conventional and organic food are equal, that is, $s_n = s_b$. But it is of interest to analyze the effects of two alternative polar situations. The first situation is the case that $s_b < s_n$. A justification for this scenario derives from the observation that organic products derive from well-specified production practices that inherently already include elements of identity preservation. Thus, one can hypothesize that there may be a smaller segregation cost for organic products, relative to conventional products, following the introduction of GM food. But the alternative of $s_b > s_n$ is also quite relevant, because organic production insists on a zero-tolerance level for the adventitious presence of GM material. Meeting this stricter standard is, of course, bound to be costlier.

The results concerning the various impact of segregation, labeling and traceability are reported in Table 3. The second column, in particular, computes the impact of the innovation if in fact all such costs were absent. However unrealistic, this scenario is useful as a benchmark. Note in particular that both producers and consumers overall would benefit from the GM innovation, so aggregate welfare increases. But the returns to organic producers would decrease in such a scenario because of the double impact of competition at the demand level (one more substitute product is available) and because of the increase in the returns to land (which causes production costs to increase for the organic industry proportionally more than in the other industries).

To ascertain the potential impact of alternative scenarios for the cost of segregating organic food, the parameter s_b is halved and doubled, respectively, while all other parameters are kept at their baseline values. The results are reported in the fourth and fifth columns, respectively, of Table 3. A lower segregation cost for organic food leads to a lower equilibrium price for organic food as expected, whereas the equilibrium prices of other goods increase. The effect on the equilibrium quantity demanded is for organic food to increase (relative to the benchmark) and for the other two products to decrease, although the magnitude of these effects is somewhat small. Per hectare rent remains higher than at the baseline, which increases the cost of production so that prices for conventional and GM food are higher compared to the baseline.

Both components of producer surplus increase relative to the baseline, whereas consumer surplus is actually lower than at the baseline (the additional decrease in organic food price does not offset the small price increases in the other two products). Overall, aggregate welfare is minimally improved (relative to the baseline). Doubling s_b has essentially the opposite effect of halving it, and therefore the economic effects are qualitatively reversed relative to the baseline.

5.3. Effects of the overall level of segregation costs

As discussed in Section 3, a wide range of segregation costs have been contemplated in previous studies, and much uncertainty remains as to their actual level because large-scale segregation of GM and non-GM products has not yet been attempted. The parameter value for segregation cost used in the baseline reflects an average of values found in previous studies, but it is of course of interest to evaluate the model's sensitivity to changes in the level of segregation cost. To that end, here we maintain the baseline's assumption that segregation costs for organic and conventional products are the same ($s_n = s_b$), and consider the effects of doubling and halving their level. The effects of former and latter scenarios relative to the baseline scenario can be seen by comparing the second (baseline) column with the sixth and seventh columns, respectively, in Table 3.

None of the results qualitatively change relative to the pre-innovation scenario, the first column in Table 3. For higher segregation costs, the equilibrium producers' prices are uniformly lower than at the baseline; at the demand level the only price that increases (relative to the baseline) is that of conventional food (the largest industry here). The production of quality food and of GM food both expand, whereas the production of conventional food decreases relative to the baseline. The gain of consumers due to the decrease in the prices of GM and quality food does not outweigh their losses due to the increase in the price of conventional food, and consumers are (as expected) negatively impacted by the larger segregation costs. Organic food producers' returns increase, as does their supply, but overall the higher segregation costs hurt producers, consumers, and aggregate welfare.

Halving the segregation costs works just the opposite of doubling them, so the results are qualitatively reversed relative to the baseline case. In particular, both GM and organic food production decrease (relative to the baseline). Overall welfare is improved but organic producers actually prefer uniformly higher segregation costs.

5.4. Effects of GM labeling and traceability costs

Labeling and traceability costs of GM food is envisioned by the current regulation in the EU, which requires that the GM content of the food must be traced back at all stages of production. This requirement clearly increases the costs of marketing GM products while it arguably does not affect the IP costs of non-GM products (which still have to undertake all the many IP activities that are required to ensure segregation at the desired purity level). In the baseline, we set the labeling and traceability costs to zero in order to disentangle their effects from those of segregation costs, which are necessary to preserve the identity of conventional and quality food.

We do sensitivity analysis by allowing this parameter to take positive values, such as one-fourth and one-half of the segregation cost for conventional food, which are presented in the last two columns in Table 3. The positive labeling and traceability costs, over and above segregation costs, have a direct negative impact on the supply price of GM food, which in turn tends to decrease the returns to land. The latter affects the unit production costs so that in equilibrium the demand prices of conventional and organic food are also lower (but the price of GM food is higher owing to the tax-like effect of the GM labeling and traceability requirements). The returns to producers of quality food are improved by labeling and traceability costs imposed on GM producers, compared to the baseline.

But the organic industry is small, and for the overall producer surplus the further drop in the returns to land tends to dominate. Consumer surplus is actually improved by positive labeling and traceability costs, because consumers can enjoy the lower equilibrium prices of conventional and organic products. Overall aggregate welfare, however, is negatively impacted (producers lose more than consumers gain).

5.5. Effects of the size of GM innovation

The parameter (γ) for cost reduction due to GM technology indexes the farmers' net benefit from adopting GM innovation. The value used in the baseline is the average of the values suggested in the literature. We now perform sensitivity analysis on this parameter by considering $\gamma = 0.99$ and $\gamma = 0.97$ (recall that the baseline had $\gamma = 0.98$). Results are reported in the third and fourth columns in Table 4 (the baseline is in the second column).

Generally speaking, it seems that the results concerning the impact of the size of the GM innovation do not change the qualitative insights obtained in the baseline. For a lower value of the γ parameter, the cost reduction from GM innovation becomes higher and GM production slightly expands. The opposite attains for the higher value of the γ parameter. The qualitative effects on prices are intuitive. As for the quantitative impacts on welfare, a larger GM innovation improves overall welfare and returns to land, relative to the baseline, but decreases consumer surplus and the returns to organic producers.

5.6. Effects of demand elasticity

The total elasticity value for aggregate food demand is found to be quite inelastic in the literature. Because we model the EU food demand as net of imports/exports, we assumed somewhat more elastic demand and set $\varepsilon = 0.4$ in the calibration stage. This parameter value governs the flexibility of aggregate demand as prices uniformly vary and can be important for the model's results. GM food innovation creates price changes in all markets: once its production becomes feasible, it will be a less expensive alternative to other products. At the same time, GM food production creates negative externality on other goods because they need to be segregated, which increases their production costs and pushes their prices up.

We halve and double the baseline value of total elasticity demand and report the results in the last two columns of Table 4, respectively, which can be compared with the baseline scenario in the second column. Once again, none of the results qualitatively change in these scenarios relative to the pre-innovation scenario shown in the first column. Overall, therefore, we should conclude that the qualitative conclusions of the baseline are robust to the choice of the demand elasticity value.

5.7. ***Effects of the parameter ϕ (the size of the population of indifferent consumers)***

Our baseline solution assumes that 25% of EU consumers are, essentially, indifferent to the GM nature of food produced from GM crops; as long as in equilibrium the new product commands a lower price (no matter how small the difference), these consumers would consume the new product. As discussed earlier, this parameterization captures an important attribute of the demand impact of the introduction of the new, weakly inferior GM products. But how important is the actual size of the parameter ϕ for our conclusions? Table 5 provides some sensitivity analysis that considers various alternative values for this parameter.

Beginning with the last column, the case of $\phi = 1$ considers a scenario in which all consumers are indifferent between GM and conventional food. In such a case the GM food completely supplants the pre-existing non-GM conventional food. This scenario would be associated with an increase in the returns to land (which would capture most of the efficiency gains of the innovation), but consumers also gain and there is a sizeable overall welfare gain. The losers in such a setting would be the organic food producers, for three reasons: because the increased returns to land increase their production costs; because the competing product at the demand level is available at a slightly lower price; and because they still have to incur segregation costs to market their non-GM organic product to consumers.

Decreasing the parameter ϕ (i.e., more and more consumers "dislike" the GM innovation) decreases overall welfare, returns to land, and consumer surplus monotonically. But organic producers prefer a lower ϕ because that means that consumers are more attracted to their product (ceteris paribus) and because they can benefit from the reduced rental price of land.

5.8. Some break-even points

To sharpen the model's prediction on the potential quantitative impacts of GM product adoption on EU agriculture and welfare, following the valuable suggestion of a reviewer, in Table 6 we report some "break-even" points of particular interest. Consider first the "size" of the innovation captured by the parameter γ. As is apparent by now, our model displays one of the insights formalized in Lapan and Moschini (2004): there is a market failure associated with the mere introduction of the new product which has a negative impact on welfare. Indeed, our baseline solution indicates that overall welfare in the EU would drop as a result of GM crop adoption, mostly because of the need for (hitherto unnecessary) segregation costs. But, as the foregoing analysis indicates, the marginal impact of the innovation may be positive (because the "externality effect" is associated with the presence of the new GM activity, and not to its level, the market failure is essentially that of a nonconvexity). So, is there a size of the innovation large enough to fully offset the aggregate negative welfare effects of the GM innovation? The answer is yes, in our model. But, as the third column in Table 6 indicates, the parameter γ would have to be extraordinarily low: $\gamma = 0.877$. That is, GM crop production would need to entail an efficiency gain exceeding 12%. Even at that, however, the break-even of aggregate welfare would be achieved at the expense of consumers and of organic food producers (both of these groups would lose).

Next, we consider the impact of segregation costs. How low would they need to be, given our other baseline parameters, for aggregate welfare not to decrease? Very low indeed, in our model, as indicated in the fourth column of Table 6. Specifically, we would need $s_b = s_n$=0.0062; i.e., segregation costs would need to account for less than 1% of the supply price. Finally, we consider the break-even point for the parameter ϕ indexing the size of the population of "indifferent" consumers. It turns out that $\phi = 0.73$ would do. This is much higher than our (conservative) baseline choice but perhaps not outside of the set of likely values. The truth of the matter is that little is known about the quantitative attributes of consumer response to GM attributes in food. Our analysis here again emphasizes the crucial importance that such preferences have on the calculation of possible market and welfare effects.

6. Conclusion

We have developed a partial equilibrium, multi-market model of the European agricultural sector, in which conventional food and quality-enhanced food (organic) exist prior to the introduction of GM products and may be differentially affected by this innovation. Whereas the model is rather stylized, it possesses some distinctive features: on the demand side, consumers have differentiated tastes with respect to these three products; on the supply side, we explicitly take into account the IP costs that GM food would impose on other goods in the equilibrium. For the organic food, we model "quality enhancement" as resulting from additional efforts supplied by producers. We endogenize the reward to these efforts and the price of land. The calibrated model is solved for equilibrium prices, quantities, and welfare changes. Finally, we carry out some sensitivity analysis on the assumed values of key parameters.

The results show that the introduction of GM products in this context reduces welfare, as well as both consumers' and producers' surplus. This conclusion differs from those of existing empirical studies, which have found a positive welfare impact of the new GM technology (e.g., Falck-Zepeda, Traxler, and Nelson, 2000; Moschini, Lapan, and Sobolevsky, 2000; Demont and Tollens, 2004), but it is in keeping with the analyses of Lapan and Moschini (2004) and Fulton and Giannakas (2004). There are at least four reasons why our results differ from the positive welfare effects found in some earlier studies. First, here we explicitly allow for differentiated consumer preferences, specifically for some consumers to have a preference for non-GM products. Second, in this model we have also assumed that it is costlier to provide non-GM products in the post-GM situation because of the need for identity preservation activities. Both of these features, ignored by the aforementioned previous studies, appear quite relevant, and their explicit consideration should improve our assessment of the economic impact of the new GM technology. Third, in this study we have also neglected the *ex post* returns to the providers of the GM innovation, for reasons discussed earlier.[16] Finally, our model explicitly models the multi-market effects of GM adoption and specifically accounts for the endogeneity of the returns to agriculture's foremost fixed input, land.

An important attribute of the GM product innovation effects highlighted by our model is the distinction between the total and marginal impact of GM innovation adoption. Such a distinction derives from the fact that we have modelled a market failure associated with the *per se* introduction of the (otherwise efficiency-enhancing) innovation. Introducing GM products entails some drastic adjustments for the agricultural sector, and hitherto unnecessary segregation activities (a real resource cost) are now necessary, which tends to decrease aggregate welfare. But given that GM products are introduced, ceteris paribus it may be desirable to have a larger rather than smaller diffusion of the product. For instance, the labelling and traceability requirements of GM products, which act as a disincentive to the (marginal) adoption of GM products, here further decrease aggregate welfare.

Another conclusion of our analysis is that the introduction of GM products actually benefits the producers of the "quality" product (organic food in our specification). Such a conclusion, of course, is bound to depend on possible differences in segregation costs for the two non-GM products. Insisting on a zero tolerance level for the adventitious presence of GM content in organic food, for

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[16] If we were interested in evaluating the ex post welfare effects of a given (available) innovation, it would possibly be desirable to account for such returns to the providers of the innovation, and that could clearly change the overall welfare picture. On the other hand, if the focus in on EU welfare, a relevant observation is that the current GM traits are mostly owned by companies located outside the EU. Indeed, some have

example, presumably requires costlier segregation activities, and that will hurt organic producers. We also show that the new EU labeling and traceability requirements do decrease the market share of GM food, to some extent, and hurt the overall returns to farmers but actually have a slightly positive impact on the welfare of consumers (through the decrease of production costs due to lower land rents).

One of the main contributions of this paper is the derivation of a model that allows for a differentiated food demand, induced by the innovation itself, which appears to be an important feature of the current generation of GM innovations. We have also shown that such an induced differentiated demand structure can be embedded in a standard equilibrium model for the agricultural sector that is suitable for welfare analysis. The results of this study are qualitatively interesting, but the actual magnitude of the market and welfare impact uncovered obviously depends on the necessarily simplified structure of the model, as well as on the actual parametric calibration that was implemented. The sensitivity analysis carried out provides some comfort as to the robustness of the results presented, but of course much scope remains for future work devoted to a more exact accounting of the many (sometimes unexpected) impacts that modern biotechnology is having on the agricultural sector.

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suggested this fact may provide an important political-economy explanation for the dramatically different treatment so far accorded to these products in the United States and the EU (Graff and Zilberman, 2004).

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Table 1- Parameters implemented in the base run

	Description	***Unit of measure***	***Values***
Primary Data			
V_T	Total value of production	*b€* (a)	248.5
V_b	Value of organic food production	*b€*	2.79
L	Total UAA in the EU	*mh* (b)	130.3
L_b	Land allocated to organic food	*mh*	3.78
π	Rent	€/*ha*	208.8
Calculated			
p_n	Price of normal food	€/*u*	1.00
p_b	Price of organic food (price index)	€/*u*	1.63
$V_n = V_T - V_b$	Value of normal food production	*b€*	245.7
$x_n = V_n$	Normal food production	*bu* (d)	245.7
$L_n = L - L_b$	Land allocated to normal food	*mh*	126.6
$1/\alpha_n = x_n / L_n$	Yield for normal food production	*u*/*ha*	1,941
$x_b = V_b / p_b$	Organic food production	*bu*	1.71
$1/\alpha_b = x_b / L_b$	Yield for organic food production	*u*/*ha*	452
$c = p_n - \alpha_n \pi$	Unit cost of market input bundle	€/*u*	0.89
$z = L_b / L$	Fraction of total land allocated to the organic production		0.029
Assumed and calibrated			
s_n	Segregation cost for normal food	€/*u* (c)	0.05
s_b	Segregation cost for organic food	€/*u*	0.05
γ	Reduction in average cost of producing GM food with respect to normal food		0.98
t	Labeling costs, traceability, and other mandatory costs for producing GM food	€/*u*	0
ϕ	The share of consumers who are indifferent between normal and GM food at the same prices		0.25
ε	Total demand elasticity		0.40
ρ	Organic production parameter		10.65

(a) billion euros
(b) million hectares
(c) euros per unit of production (u)
(d) billion of units of production

Table 2 - Baseline scenario results
(Note: See Table 1 for the values of parameters implemented)

		Values		***Variation***	
Variable	U.M.	Pre-innovation	Post-innovation	Level	%
Demand prices					
normal food (p_n)	€/*u*	1.00	1.026	0.026	2.55
organic food (p_b)	€/*u*	1.63	1.584	-0.046	-2.83
GM food (p_g)	€/*u*	>1.00	0.958	-0.055	-5.44
Producer prices					
normal food ($p_n - s_n$)	€/*u*	1.00	0.976	-0.024	-2.45
organic food ($p_b - s_b$)	€/*u*	1.63	1.534	-0.096	-5.90
GM food ($p_g - t$)	€/*u*	>1.00	0.958	-0.055	-5.44
Food Production					
normal food (x_n)	*bu* [a]	245.71	170.31	-75.41	-30.69
organic food (x_b)	*bu*	1.71	1.77	0.06	3.30
GM food (x_g)	*bu*	0.00	75.17	75.17	NA
Total segregation costs	*b*€	0.00	8.60	8.60	NA
Unit rent for land (π)	€/*ha*	208.79	161.24	-47.55	-22.78
Total Rent	*b*€ [c]	27.21	21.02	-6.20	-22.78
Profits of organic producers	*m*€ [d]	235.57	251.35	15.78	6.70
Producers' surplus	*b*€	27.45	21.27	-6.18	-22.52
Consumers' surplus	*b*€			-1.55	
Aggregate welfare	*b*€			-7.73	

[a] Billion units
[b] Million hectares
[c] Billion Euros
[d] Million Euros

Table 3: Results for the simulations on segregation and labeling costs

Variable	U.M	Pre-innovation	Post-innovation								
			Zero Segregation costs	Baseline solution	Different segregation costs for organic and conventional		Different levels of same segregation costs		Labeling and traceability costs	
			$s_b = 0$ $s_n = 0$	$s_b = B$ [(a)] $s_n = B$	$s_b = 0.5B$ $s_n = B$	$s_b = 2B$ $s_n = B$	$s_b = 0.5B$ $s_n = 0.5B$	$s_b = 2B$ $s_n = 2B$	$s_b = s_n = B$ $t = s_n/4$	$s_b = s_n = B$ $t = s_n/2$
Consumer prices											
normal food (p_n)	€/u	1.00	1.0044	1.0255	1.0262	1.0241	1.0141	1.0530	1.0208	1.0165
organic food (p_b)	€/u	1.63	1.6460	1.5839	1.5655	1.6211	1.6117	1.5463	1.5666	1.5509
GM food (p_g)	€/u	>1.00	0.9865	0.9577	0.9584	0.9563	0.9713	0.9352	0.9654	0.9736
Producer prices											
normal food ($p_n - s_n$)	€/u	1.00	1.0044	0.9755	0.9762	0.9741	0.9891	0.9530	0.9708	0.9665
organic food ($p_b - s_b$)	€/u	1.63	1.6460	1.5339	1.5405	1.5211	1.5867	1.4463	1.5166	1.5009
GM food ($p_g - t$)	€/u	>1.00	0.9865	0.9577	0.9584	0.9563	0.9713	0.9352	0.9529	0.9486
Normal food production (x_n)	bu [b]	245.71	180.70	170.31	170.25	170.41	175.48	160.20	172.80	175.29
Organic food production (x_b)	bu	1.71	1.69	1.77	1.79	1.72	1.73	1.82	1.78	1.80
GM food production (x_g)	bu	0.00	65.08	75.17	75.13	75.24	70.14	85.04	72.60	70.03
Segregation and labeling costs	b€	0.00	0.00	8.60	8.56	8.69	4.43	16.20	9.64	10.61
Unit rent for land (π)	€/ha	208.79	217.26	161.24	162.65	158.52	187.64	117.64	152.07	143.71
Total Rent	b€ [d]	27.21	28.32	21.02	21.20	20.66	24.46	15.33	19.82	18.73
Profits of organic producers	m€ [e]	235.57	230.97	251.35	257.48	239.61	241.65	267.15	256.61	261.59
Producers' surplus	b€	27.45	28.55	21.27	21.46	20.90	24.70	15.60	20.08	18.99
Variation in consumers' surplus	b€	-	0.03	-1.55	-1.69	-1.27	-0.61	-4.23	-1.28	-1.09
Variation in aggregate welfare	b€	-	1.13	-7.73	-7.69	-7.82	-3.37	-16.08	-8.66	-9.55

Notes: (a) B = Base Value; (b) Billion units; (c) Million of hectars; (d) Billion of euros; (e) Million of euros.

Table 4: Sensitivity analysis on parameter for cost reduction due to GM technology (γ) and total elasticity value (ε)

		Pre-innovation	Post-innovation				
			Baseline solution	Effect of size of innovation (parameter γ)		Effect of demand elasticity (parameter ε)	
Variable	U.M		$\varepsilon = 0.4$ $\gamma = 0.98$	$\varepsilon = 0.4$ $\gamma = 0.97$	$\varepsilon = 0.4$ $\gamma = 0.99$	$\varepsilon = 0.2$ $\gamma = 0.98$	$\varepsilon = 0.8$ $\gamma = 0.98$
Consumer prices							
normal food (p_n)	$€/u$	1.00	1.0255	1.0291	1.0221	1.0304	1.0229
organic food (p_b)	$€/u$	1.63	1.5839	1.5972	1.5714	1.6031	1.5738
GM food (p_g)	$€/u$	>1.00	0.9577	0.9524	0.9632	0.9626	0.9551
Producer prices							
normal food ($p_n - s_n$)	$€/u$	1.00	0.9755	0.9791	0.9721	0.9804	0.9729
organic food ($p_b - s_b$)	$€/u$	1.63	1.5339	1.5472	1.5214	1.5531	1.5238
GM food ($p_g - t$)	$€/u$	>1.00	0.9577	0.9524	0.9632	0.9626	0.9551
Normal food production (x_n)	bu [b]	245.71	170.31	168.54	172.08	171.05	168.95
Organic food production (x_b)	bu	1.71	1.77	1.75	1.78	1.75	1.77
GM food production (x_g)	bu	0.00	75.17	77.00	73.33	74.47	76.50
Total segregation costs	$b€$	0.00	8.60	8.51	8.69	8.64	8.54
Unit rent for land (π)	$€/ha$	208.79	161.24	168.27	154.61	170.78	156.22
Total Rent	$b€$ [c]	27.21	21.02	21.93	20.15	22.26	20.36
Profits of organic food producers	$m€$ [d]	235.57	251.35	247.45	255.13	247.98	253.05
Producers' surplus	$b€$	27.45	21.27	22.18	20.41	22.51	20.62
Variation in consumers' surplus	$b€$		-1.55	-1.78	-1.35	-2.81	-0.85
Variation in aggregate welfare	$b€$		-7.73	-7.05	-8.39	-7.76	-7.69

Notes: (a) B = Base Value; (b) Billion; (c) Million of hectars; (d) Billion of euros; (e) Million of euros.

Table 5: Sensitivity analysis on parameter ϕ (size of the population of indifferent consumers)

			Post-innovation				
			Baseline solution	Effect of size of indifferent consumers (parameter ϕ)			
Variable	U.M	Pre-innovation	$\phi = 0.25$	$\phi = 0.125$	$\phi = 0.5$	$\phi = 0.75$	$\phi = 1$
Consumer prices							
normal food (p_n)	$€/u$	1.00	1.0255	1.0189	1.0387	1.0517	1.0646
organic food (p_b)	$€/u$	1.63	1.5839	1.5600	1.6316	1.6793	1.7268
GM food (p_g)	$€/u$	>1.00	0.9577	0.9510	0.9708	0.9838	0.9967
Producer prices							
normal food ($p_n - s_n$)	$€/u$	1.00	0.9755	0.9689	0.9887	1.0017	1.0146
organic food ($p_b - s_b$)	$€/u$	1.63	1.5339	1.5100	1.5816	1.6293	1.6768
GM food ($p_g - t$)	$€/u$	>1.00	0.9577	0.9510	0.9708	0.9838	0.9967
Normal food production (x_n)	bu a	245.71	170.31	199.10	113.07	56.31	0.00
Organic food production (x_b)	bu	1.71	1.77	1.79	1.71	1.66	1.61
GM food production (x_g)	bu	0.00	75.17	46.25	132.63	189.62	246.14
Total segregation costs	$b€$	0.00	8.60	10.04	5.74	2.90	0.08
Unit rent for land (π)	$€/ha$	208.79	161.24	148.36	186.79	212.08	237.12
Total Rent	$b€$ c	27.21	21.02	19.34	24.35	27.64	30.91
Profits of organic food producers	$m€$ d	235.57	251.35	259.54	236.05	222.06	209.25
Producers' surplus	$b€$	27.45	21.27	19.60	24.58	27.86	31.11
Variation in consumers' surplus	$b€$		-1.55	-1.90	-0.83	-0.10	0.64
Variation in aggregate welfare	$b€$		-7.73	-9.75	-3.70	0.31	4.31

Notes: (a) Billion units; (b) Million of hectars; (c) Billion of euros; (d) Million of euros

Table 6: Break-Even Analysis

			Post-innovation			
		Pre-innovation	Baseline solution	Break-even value of given parameter (all other parameters held at baseline value)		
Variable	U.M			$\gamma = 0.8774$	$s_b = s_n$=0.0062	$\phi = 0.7305$
Consumer prices						
normal food (p_n)	$€/u$	1.00	1.0255	1.0723	1.0066	1.0507
organic food (p_b)	$€/u$	1.63	1.5839	1.7592	1.6369	1.6755
GM food (p_g)	$€/u$	>1.00	0.9577	0.9130	0.9826	0.9828
Producer prices						
normal food ($p_n - s_n$)	$€/u$	1.00	0.9755	1.0223	1.0004	1.0007
organic food ($p_b - s_b$)	$€/u$	1.63	1.5339	1.7092	1.6307	1.6255
GM food ($p_g - t$)	$€/u$	>1.00	0.9577	0.9130	0.9826	0.9828
Normal food production (x_n)	bu [a]	245.71	170.31	152.58	179.40	60.72
Organic food production (x_b)	bu	1.71	1.77	1.60	1.70	1.66
GM food production (x_g)	bu	0.00	75.17	93.58	66.34	185.19
Total segregation costs	$b€$	0.00	8.60	7.71	1.13	3.12
Unit rent for land (π)	$€/ha$	208.79	161.24	252.18	209.59	210.12
Total Rent	$b€$ [c]	27.21	21.02	32.87	27.32	27.39
Profits of organic food producers	$m€$ [d]	235.57	251.35	207.77	233.70	223.11
Producers' surplus	$b€$	27.45	21.27	33.08	27.55	27.61
Variation in consumers' surplus	$b€$		-1.55	-5.63	-0.10	-0.16
Variation in aggregate welfare	$b€$		-7.73	0.00	0.00	0.00

Notes: (a) B = Base Value; (b) billion units (c) Million of hectars; (d) Billion of euros; (e) Million of euros.

Appendix to Chapter 3

A. 1. On the value of quality food production (v_b) and price of quality food (P_b)

Hamm, Friederike, and Darren (2002) provides country and product based data on the production of organic food, price of organic food, price premium for organic food in European Union (EU) in year 2000. Moreover, EU DG of Agriculture (2003) provides country and product based data on prices and production levels for an extensive set of products of agricultural market in EU including year 2000. Because the latter data refer to both organic and conventional food, we can only calculate the value and the level of total production on a product and country base. Combining both sources of data, we estimate the prices and production levels for conventional food on various goods and present in Table A.1.

Note that Hamm, Friederike, and Darren (2002) reports the organic production levels but not the prices and price premiums at the farm level for vegetables, fruits, and olives. Because the combined market share of these groups is significant in the organic sector (ITC, 2001), we want to exploit the quantity data provided on these groups in Hamm, Friederike, and Darren (2002).

Regarding olives, we presume that Hamm, Friederike, and Darren (2002) reports for table olives given the large size of the production they reported, which corresponds to the 10% of the EU olive oil production (EU DG for agriculture, 2003). Note that the EU data for olive oil include table olives in olive oil equivalent (EC DG for agriculture, 2003). Similarly, we find the olive oil equivalent of table olives in Hamm, Friederike, and Darren (2002) based on the measure that on average it takes 5 kg olives to produce 1 liter (corresponds to 1kg in terms of mass) olive oil and report on Table A.1.[17]

The levels of total production on a country basis are available for vegetables and fruits in EU DG for Agriculture (2003), and for olive oil in EC DG for Agriculture (2002). Note that the former

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[17] Based on the text written by Executive Secretariat of the International Olive Oil Council (IOOC) on the Federation of Oils, Seeds and Fats Associations (FOSFA)'s webpage, which is available at: http://www.fosfa.org/resources/res_seeds_complete.pdf

source reports on the total production only at EU level for olive oil, which is consistent with the latter source, nevertheless, the prices for olive oil types on a country basis are available in EU DG for Agriculture (2003). Based on the available data on prices of a set of products belonging to each group, we calculate an average price for each group for a given country.[18] Using this average price and the total production, we calculate the value of production for each group in a given country. Furthermore, we make the assumption that the price premium for vegetables, fruits, and olive oil is the same with the average price premium on remaining organic products in a given country. Combining the estimated value of production, total production and price premium with the organic production reported in Hamm, Friederike, and Darren (2002), we can calculate the prices for organic and conventional food and quantities of conventional food for each group in a given country. Then, the weighted EU average for organic and conventional prices for each group is calculated in a similar manner with Hamm, Friederike, and Darren (2002) and reported in Table A.1.

Based on the data in Table A.1, the value of quality food production and the Fisher price index can be calculated as $v_b = 2{,}785{,}390{,}786$ euros, and $P_b = 1.63$, respectively.

A.2. References:

European Commision (EC) Directorate-General for Agriculture. 2002. The *Olive Oil Sector in the European Union*, available on the World Wide Web at: http://europa.eu.int/comm/agriculture/publi/fact/oliveoil/2003_en.pdf.

EU Directorate-General for Agriculture. 2003. *Agriculture in the European Union-Statistical and Economic Information 2002*, available on the World Wide Web at: http://europa.eu.int/comm/agriculture/agrista/2002/table_en/en31.htm.

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[18] It is the weighted average for vegetables, (where the weights are the share of value of each product within the value of set of products considered for this group), the weighted average of the arithmetically averaged prices for fruit categories, citrus fruits and non-citrus fruits based on the distinction in EU DG for Agriculture (2003), (where the weights are the share of value of each fruit category within total value of fruit production), and the arithmetic average for olive oil. Note that the products for which prices are available on a country basis are cauliflowers, tomatoes, and aubergines for vegetables; oranges, mandarins, lemons, celementines and satsumas for citrus fruit, and apples, pears, peaches, nectarines, apricots, table grapes, water melons, melons, and strawberries for non-citrus fruit; and extra virgin olive oil, lampante grade olive oil 3°, and refined olive oil for olive oil.

Hamm, U., G. Friederike, and H. Darren. 2002. *Analysis of the European market for organic food*, OMIaRD, vol. 1, School of Management and Business, Aberystwyth, University of Wales.

International Trade Center (ITC), 2001. *World markets for Organic Fruit and Vegetables*, available at http://www.intracen.org/mds/sectors/organic/welcome.htm

Table A.1
Prices, (€/100kg or specified)
Quantities produced (tonnes or specified) at farm gate level, 2000

Products	p_b[a]	p_n[b]	q_b[a]	q_n[b]
Cereals	24	12	1,527,095	212,245,636
Potatoes	32	11	298,998	48,292,917
Oilseeds	33	17	43,678	14,046,332
Wine[c]	97	76	1,229,999	177,662,001
Milk	37	31	1,125,225	119,842,775
Beef	303	286	47,367	7,193,633
Sheep	444	360	5,691	1,137,537
Pork	225	128	31,217	17,545,335
Poultry	252	113	12,447	8,793,353
Eggs[d]	0.150	0.063	999	82,120
Vegetables[e]	137	63	570,563	54,357,798
Fruits[e]	76	52	562,842	33,365,151
Olive oil[e, f]	277	187	50,589	2,001,157

[a] Source: Hamm, Friederike, and Darren (2002) or specified.
Note: the organic production corresponds to the organic production sold as organic.
See Hamm, Friederike, and Darren (2002) for the distinction.

[b] Estimates based on Hamm, Friederike, and Darren (2002) and EU DG of Agriculture, 2003

[c] Price €/hl, quantities in hl

[d] Price €/piece, quantities in million pieces

[e] Organic prices are estimates

[f] Organic quantity is equivalent of that for table olives reported in Hamm, Friederike, and Darren (2002)

CHAPTER 4. AN EMPIRICAL ANALYSIS OF LICENSING RENTS OF U.S. UNIVERSITIES

Abstract

Since the Bayh-Dole Act of 1980 made it possible for universities and other non-profit organizations to retain title to patents derived from federally funded research, there has been a dramatic surge in patenting by U.S. universities. This time period was also characterized by fundamental legal and institutional changes favoring stronger intellectual property rights. This growth in university patenting and licensing activities has resulted in a considerable debate on how these activities have affected the traditional role of universities (advancement of science and dissemination of knowledge) and on whether the Bayh-Dole Act was in fact necessary to promote technology transfer. This paper aims to contribute to this discussion by empirically studying a basic yet somewhat unexplored question: "What can universities expect in terms of economic returns from patenting and licensing activities?".

1. Introduction

The Bayh-Dole Act of 1980 made it possible for universities and other non-profit organizations to retain title to patents derived from federally funded research. The establishment of the Court of Appeals for the Federal Circuit in 1982, which strengthened patent protection, and U.S. Supreme Court decisions in 1980 (e.g. Diamond vs. Chakrabarty and Diamond vs. Diehr), which led the way to the patenting of organisms, molecules and research techniques in biotechnology and allowed for the patentability of applications of laws of nature and mathematical formulae, respectively), were also very important policy developments. Contemporaneous with these policy shifts in favor of intellectual property rights (IPRs), more and more universities became directly involved in licensing activities through their own technology transfer offices (TTO). The number of universities with a technology transfers office increased from 25 in 1980 to 200 in 1990, and by 2000 almost all U.S. universities had such an office (Nelson, 2001). Moreover, the growth of U.S. universities' patenting and licensing activities, which began in the 1970s, accelerated in the last decade (Sampat, 2003). A 15-fold increase in university patenting and a dramatic increase (more than 5-fold) in the number of universities granted patents were observed between 1965 and 1992 (Henderson, Jaffe and Trajtenberg, 1998). For 69 U.S. universities, that are nine-year recurrent respondents to Association of the University Technology Managers (AUTM) surveys, U.S. patents issued to these universities increased 129% between 1993 and 2001. Licenses and options executed by 55 U.S. universities, that are eleven-year recurrent respondents to AUTM surveys, increased 139% between 1991 and 2001. The gross license revenue received by 56 universities that are eleven-year recurrent respondents to AUTM surveys increased 485% between 1991 and 2001. The total number of licenses and options executed by 156 U.S. universities was 3,739 in FY 2002, which generated nearly $1 billion in that year as gross license revenue (AUTM 2002).

This growth in university patenting and licensing activities created a recent discussion in the literature (Sampat, 2003, Link, Scott and Siegel, 2003, Nelson, 2001, Mowery et al., 2001, Jaffe, 2000) that has revolved around how these activities have affected the traditional role of universities, typically understood to be the advancement of science and the dissemination of knowledge, and whether Bayh-Dole was necessary to induce the technology transfer and provided the right incentives for universities. The consensus is that Bayh-Dole created a favorable normative environment where universities can be active on the business side of their research. At the same time, it created incentives to generate economic returns from academic research, which is thought to be open to exploitation. Universities can do these activities based on their self interest, rather than public interest, which may diverge to some degree. Although the Act was intended for inventions that would not be developed and commercialized without patenting and licensing, universities can exploit these rights by applying them to all patentable inventions. There are examples, such as the Cohen-Bayer recombinant DNA technique licensed by University of California and Stanford University and Richard Axel's co-transformation process patented and licensed by Columbia University, for which technology transfer would occur absent patenting and licensing, and by doing so universities simply taxed the industry and eventually consumers (Sampat, 2003). Furthermore, how the other channels of disseminating knowledge and technology transfer, such as publications and conferences, are affected from the growth in the patenting and licensing activities is not known yet. Scientific research may suffer from restricted availability of, and access to, information and materials and research tools, which are inputs to further research. Universities may change their composition of patenting towards basic science, which may reduce the optimal use of knowledge, depending on the licensing arrangements. Moreover, the perception of universities as service organizations may be jeopardized. For instance, increasing patenting and licensing activities and resulting litigations, may create tension between industry and universities because some firms think that the competition is unfair as universities are supposed to be non-profit organizations and are publicly subsidized (Nelson, 2001).

Because increased revenue is one of the considerations motivating universities in this context, a relevant question may be whether universities are collecting considerable net revenue from these activities. Figure 1 presents the distribution of net license revenues (license revenues received net of legal fees paid, but without taking into account the operating cost of technology transfer offices) for 173 US universities, averaged over the five-year period 1998 to 2002. The observations are ranked in descending order, which makes it apparent that only a few universities are earning large revenues. In fact, the top 20 of universities in terms of net license revenue are obtaining 76% of the total positive net license revenue generated. It is apparent that the majority of universities either earn negative profit or break even. It is perhaps more informative, if the net license revenues are normalized by the research expenditures. Figure 2 presents the distribution the net license revenues normalized by the research dollars, which is also skewed to the right. For a few universities this ratio is high, but for the majority of them (84%) it is less than 3%. Note also that the big revenue earners in Figure 1 are not necessarily those with high ratios in Figure 2. For example, the University of California System has the second largest net license revenue but that is only 3% of its total research budget. Moreover, Columbia University earns the highest net license revenue ($111 million), whereas Florida State University is receiving the highest gross revenue relative to its research budget (42%).

Nevertheless, the overall picture shows that a few universities are earning large revenues, whereas others are continuing on these activities even though they appear to earn negative net revenues or break even at best. One can claim that universities have motives other than earning positive net revenues, such as to serve the faculty in commercializing their inventions and/or promote local economic development through technology transfer. However, one can not claim that those universities with large revenues do not have such motives. Furthermore, universities can have official long-term objectives targeting public goods but the managers of TTO as agents can have short-term horizon and give priority to monetary returns in their activities. In fact, based on a recent survey of 76 major US universities, the licensing income generated is found to be the most important criterion by which TTO offices measure their success (Thursby, Jensen and Thursby, 2001). Moreover, in a theoretical study, Beath, et al. (2003) considered the possibility that universities, with tight budgets, could provide incentives to faculty to engage in applied research and consulting, which can augment the inventors' income and relax the university's budget.

Therefore, one can hypothesize as well that, as long as there are examples of big winners among universities, others (especially those entered to these activities recently) can anticipate the potential for generating extra revenue to help with their budget and expect to be successful in the future. In other words, the reason that a majority of universities are continuing with these activities even though they appear to incur economic losses could be that they are earning economic rent in expectation. Therefore we want to ask: what can U.S. universities expect in terms of economic returns from patenting and licensing activities? This question is basic and yet somewhat unexplored and motivates our study. In the next section we review some related studies that looked at the licensing revenues of US universities.

2. Literature Review

Trune (1996) analyzed the licensing activities of U.S. universities with the purpose of developing a "national criterion" with which universities can measure their performance. He mainly used data from AUTM licensing surveys between fiscal years 1991 and 1994, and other sources for university characteristics. He categorized the universities based on their differences regarding the research and teaching priorities, research emphasizes, research budgets and other factors. He calculated mean performance measures on some licensing activities for each group and found dramatic differences between groups. He also carried out some regression analysis for the whole sample of universities and for each group, a procedure which we think has shortcomings. For instance, he regressed the "license income received" on "number of active licenses" and "licenses generating royalties", both of which turned out to be significant and some other variables, which turned out to be insignificant. First, it is not surprising that license income can be explained by number of active licenses if there is no cost consideration. Second, licenses generating royalties are a subset of number of active licenses; therefore, having both of them in the regression is not meaningful. He argued that the reason that insignificant variables turned out to be so was the other significant variables in the regression and dropped the insignificant variables from the regression. In conclusion, Trune (1996) simply explained the gross licensing income with the number of licenses generating income. Furthermore, he did not apply diagnostic tests other then checking R-square and individual t-tests for the variables in his regressions.

Trune and Goslin (1998) calculated the profitability of technology transfer programs of universities by using mainly the data from the AUTM 1995 survey and some other sources for university characteristics. They defined the profit from maintaining TTOs as the one third of licensing revenues (which is taken as the share of TTO) net of cost of maintaining TTOs (personnel and overhead costs). Based on this measure, they found that nearly 60% of the universities are earning negative profits from maintaining technology transfer offices. They further defined the profit from maintaining overall technology transfer programs as the two third of licensing revenues (as the sum of shares of TTO and inventor's department) net of cost of maintaining TTOs as previously defined and net cost of patenting (patent expenses less reimbursed legal fees). Based on this measure, they found that nearly half of the institutions obtained negative profit from overall technology transfer programs. They also attempted to measure the local communities' benefits by assuming that all the costs of technology transfer programs (except those paid to US patent and trademarks office), the research grants obtained from these activities and the inventors' share from license revenues are spent in the local community. They found that these institutions put $434 million on aggregate and $2.37 million on average to their local economies. However, these figures were calculated without any net benefit or opportunity cost considerations regarding these technology transfer programs. They also categorized the universities based on their differences and did all the previous calculations for each category and made comparisons.

Siegel, Waldman and Link (2003) performed a productivity analysis of TTOs for 113 US universities by using stochastic frontier estimation (SFE) approach. Their focus was on technology transfer activities between universities and industry. They took the number of license agreements and license revenues as proxies for technology transfer activities and carried out separate estimations for each of them. The latter as a proxy can be problematic to begin with, because the goals of technology transfer and revenue generation are not necessarily tied together and may not be consistent with each other as pointed out earlier. They applied a knowledge production function approach, whereby technology transfer is produced by the inputs of TTO (measured by the number of TTO staff), external lawyers (measured by external legal expenses), and faculty inputs (measured by the number of disclosures to TTO). Moreover, the deviations from the production frontier due to inefficiency were modeled to be a function of external/institutional and organizational factors. For the former, they considered the age of TTO, whether university has a medical school, whether it is a public and some other variables indicating local industry and state conditions, which are outside of control of TTOs. They argued that organization factors are not systematically measurable nor are clearly identified in the literature.

Even though their main data source (AUTM surveys) covered the time period between 1991 and 1996, they used the annual averages of the variables over the sample period rather than constructing a panel. They argued that because some of the universities did not continuously respond to the survey during the survey period, it would be problematic to work with an unbalanced panel and wanted to keep as many universities as possible in the sample for the precision of production function estimation. They performed maximum likelihood estimation of the frontiers and found the coefficients of inputs to be significant, with signs as expected. Regarding the coefficients of variables of inefficiency equation (which models the deviations from production frontier due to inefficiencies), their signs were found to be as expected except for the mixed result for the sign of medical school dummy variable. Although the joint significance of the coefficients of the variables, which captured the inefficiency effects was confirmed, most of the coefficients individually turned out to be insignificant. They thought that omitted organizational variables, which are not measurable, caused this problem. Therefore they concluded that, in order to fully explain the deviations from the production frontier due to inefficiency, they needed to explore organizational practices. To this end, they interviewed the parties involved in technology transfer activities at five US universities on the nature of technology transfer process and reported their findings from these interviews.

Finally, Lach and Schankerman (2003) studied the question of whether the economic incentives provided to academic researchers in the licensing arrangements (in the form of royalty sharing rules) affected the number and commercial value of inventions generated in universities. Based on panel of 102 US universities for the period 1991-1999, they found that universities with higher royalty shares to inventors significantly generated higher license revenues although they appear to receive less number of disclosures to their technology transfer offices. The negative effect on the disclosures was attributed to the possibility that increased royalty shares encouraged inventors to disclose the inventions with higher commercial potential rather than reporting plenty of inventions with less commercial prospect. The effect on revenue generation was found to be much stronger in the sub sample of private universities compared to the sub sample of public universities. Moreover, the effect on the disclosures received disappeared and turned out to be positive in the former, whereas it remained negative in the latter.

3. The Modeling Framework

In order to analyze the licensing rents of universities, we use the following linear population model,

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_{K-1} x_{K-1} + u \qquad (1)$$

where y denotes the dependent variable, x_k denote the explanatory variables, β_i denotes coefficients to be estimated, and observable random scalars, u is the unobservable random term. The variables to be used in the model are as follows.

Dependent variable:

Licensing rent: In a given year, this is calculated as the total license revenue less the cost of patenting and licensing activities. The cost is measured as the sum of operating expenditures of TTOs (salary expenses plus benefits to the employees and overhead cost)[1] and net legal fees expenditures (legal fees expended less legal fees reimbursed).[2] Then, it is averaged over the sample period 1998 to 2002. Figure 3 presents the distribution of the licensing rent, which is ranked in descending order and Table 1 presents the top 20 universities in terms of licensing rent.

Explanatory variables:

Quality of the faculty: The quality of inventions obviously matters, which can be presumed to be positively associated with the quality of faculty. For the quality of faculty, we take the total number of citations per faculty in technological departments.[3] This is in level and obtained from the National Survey of Graduate Faculty done in 1993 (Research-Doctorate Programs in the United States, 1995).

The size of the university: This is measured by total research expenditures. The question of interest is whether the size of the university matters as we control for the quality of faculty.

Whether the university has a medical school: Biomedical research has emerged as a productive field whose research output attracted the interest of industry, and this trend was present before the passage of the Bayh-Dole Act (Mowery, Nelson, Sampat and Ziedonis, 2001). Hence, having a

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[1] See the Appendix for detailed discussion of the procedure used to construct the operating cost of TTOs.

[2] Legal fees expended are the expenditures of an institution on external legal fees, which include prosecuting, maintenance and interference costs of patents and copyrights. They also include minor litigation costs. Legal fees reimbursed are the legal fees expenditures reimbursed to the institution by licensees (See, AUTM, 2002).

[3] Alternative indexes are "Scholarly quality of faculty (ratings) in technological departments" and the "Number of publications per faculty in technological departments". Note that we normalize the citations received at each technological department by the number faculty in that department and sum over these departments in order to obtain total number of citations per faculty in technological departments in a given university. Lach and Shankerman (2003) further classifies these departments as six technological fields. The fields and the corresponding departments for each field stated within the brackets are **Computer Science** (Computer science), **Chemical Science** (Chemistry, Chemical Engineering), **Engineering** (Aerospace Engineering, Civil Engineering, Electrical Engineering, Industrial Engineering, Material Engineering, and Mechanical Engineering), **Biomedical and Genetics** (Biomedical Engineering, Biochemistry and Molecular Biology, Cell and Develop Biology, Molecular and General Genetics), **Other Biological Sciences** (Neurosciences, Pharmacology, Physiology, and Ecology, Evolution and Behavior), **Physical Sciences** (Astrophysics, Astronomy, Oceanography, Statistics and Biostatistics, Mathematics, Geology, Physics).

medical school is expected to provide a significant advantage in terms of generating rent from licensing activities.

Given the available invention set, the input of TTO staff, by combining labor, skill, experience and expertise comes into the picture. Here, additional explanatory variables are:

The age of the technology transfer office: This is proxy for the experience of TTO and calculated by 2002.

Exclusivity of licenses and the size of licensees: In the sample period we cover, AUTM surveys provide detailed data on whether licenses are executed exclusively or non-exclusively and to start-up, small or large companies. That provides a rich set of variables such as the share of licenses executed exclusively, the share of licenses executed to small companies, etc. Recall that one of the aims of the Bayh-Dole Act was to encourage licensing to small and/or start-up companies and the main presumption of the Act was that exclusive licensing is often necessary as an incentive to develop university inventions that requires significant amount of fixed investment.

Whether university is public or private: As public universities are more vulnerable to budget crises (Link, Scott, and Siegel, 2003), they may license more aggressively. On the other hand, public universities may culturally and bureaucratically be less flexible in interacting with private companies (Siegel, Waldman, and Link, 2003), therefore, ceteris paribus, they may have a lower licensing rate.

State R&D intensity: The performance of TTO office will also depend on the location of the universities and the local conditions that are mostly out of university's control. Here, we take the share of state-level R&D within national R&D performance in order to measure ongoing R&D activity in that state. This is also averaged over the sample period 1998 to 2002. Table 2 presents the R&D intensity for top 20 universities' states, where a systematic relationship between the rank of universities in licensing rent and state R&D intensity is not apparent.

One may argue that the current shocks to the license rent equation can potentially affect some of the explanatory variables such as the quality of faculty, size of the university in terms of total research expenditures, the share contracts that are licensed exclusively to large companies in the future. Then, the covariance between these explanatory variables and the disturbance term may not be zero, which violates Assumption 1.a. In such a case, OLS estimators would lose the consistency property. For the quality variable, it is based on citations measured in 1993; therefore, can be assumed as exogenous for the sample period we covered, which is 1998 to 2002. For other variables, because we work with the averages of these variables over the sample period, these potential effects (if any) may be mitigated.

One might also be concerned about the possible effects of some university specific organizational variables on the explanatory variables. These can be culture and bureaucracy, and the resolution of possibly multiple objectives among the parties (university scientist, administration, TTO staff, outside companies) to the technology transfer activities within a given university as these parties have different opinions regarding these activities (Thursby, Jensen, and Thursby, 2001 and Siegel, Waldman, and Link, 2003). However, these organizational effects are not easily measurable, in fact there is no consensus over what to measure (Siegel, Waldman, and Link, 2003). The variables such as the age of the technology transfer office and whether university is public or private, will also capture the effects of these organizational variables to some extent.[4] In the next section, we elaborate more on our data sources for the variables introduced here.

4. Data

The major source of data is AUTM (Association of the University Technology Managers) surveys, which provide annual data for the U.S. universities covering the period of 1991 to 2002. We focus on

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[4] The royalty sharing policy of universities for licensing activities would be a better variable to reflect how the rights of parties to the technology transfer policy are balanced but we do not have available data.

the last five years from 1998 to 2002 as this is the only time period where some data on the operating cost of technology transfer offices are available. The number of U.S. universities responding to the AUTM survey was 156 in 2002, although they are not all recurrent respondents in this period. Pooling the observations over the five year time period 1998 to 2002 yields an initial sample of 180 U.S. universities over this time period. Nevertheless, after adjusting for the missing observations on various variables, we are left with the final sample of 148 observations from U.S. universities that are used in the estimations. The survey includes various data on licensing activities of universities including the total research expenditures, the number of disclosures received, the number of new patent applications filed, the number of active licenses, the number of licenses executed by the universities, the number of licenses generating revenues, license revenues received, legal fees expended, and legal fees reimbursed. The surveys also have data on university characteristics such as the technology transfer program start date, and whether a university has a medical school, whether it is public or private, the location of the university, and the number of TTO staff.

The other source for university characteristics, such as citations received per program faculty, number of faculty in a given program, scholarly quality of program faculty, etc. is the 1993 National Survey of Graduate Faculty (Research-Doctorate Programs in the United States, 1995). The main source for salary data is College and University Personnel Association (CUPA) administrative compensation surveys, which provide data for the two key positions in TTO for the period of 1998 to 2002.[5] Combining the employment data from AUTM surveys and salary data from CUPA surveys, we estimate the operating expenses of TTOs as discussed in detail in the first section of the Appendix. Finally, the data on state and national level R&D expenditures is obtained from the National Science Foundation's website.[6]

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[5] See the webpage at http://www.cupahr.org about more information about this organization.

[6] See the website at http://www.nsf.gov/sbe/srs/sepro/start.htm for more information.

5. Estimation procedure

Recall that the model to be estimated can be written as:

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_{K-1} x_{K-1} + u \tag{2}$$

where $y, x_1, x_2, \ldots., x_{K-1}$ are observable random scalars, u is the unobservable random disturbance term and $\beta_0, \beta_1, \ldots, \beta_K$ are the parameters we would like to estimate. We make the following assumptions on the population moments:

Assumption 1.a. $E(\boldsymbol{x}'u) = 0$

Assumption 2. rank $E(\boldsymbol{x}'\boldsymbol{x}) = K$

where $E[.]$ is the expectation operator and $\boldsymbol{x}$ is the $K \times 1$ vector of explanatory variables (which includes the intercept). Assumption 1 means $E(u) = 0$ because the intercept term is included in the vector $\boldsymbol{x}$ and the disturbance term u is uncorrelated with the each of the regressors. Assumption 2 means that the (population) variance matrix of the $(K-1) \times 1$ non constant variables in $\boldsymbol{x}$ is non-singular. Assumption 2 is a standard assumption and fails only if one of these variables can be written as exact linear combination of the others.

One can assume a stronger assumption instead of Assumption 1.a.

Assumption 1.b. $E[u \mid \boldsymbol{x}] = 0$

which further ensures that the disturbance term u is uncorrelated with any non-linear functions (such as cross-products or power functions) of the $(K-1)\times 1$ non constant variables in $\boldsymbol{x}$.

Provided with a random sample of N observations from the population, that is, $\{(y_i, \boldsymbol{x}_i) : i = 1,\ldots,N\}$ independently and identically distributed, where the subscript i indexes each observation, we can write equation (1) as

$$y_i = \boldsymbol{x}_i{}'\boldsymbol{\beta} + u_i \qquad i = 1,\ldots,N \tag{3}$$

Under Assumptions 1.a and 2, OLS using a random sample consistently estimates the parameters in equation (2). Under Assumption 1.b. OLS estimates are unbiased, that is $E[\hat{\beta} \mid X] = \beta$ if $X'X$ is non-singular where X is $N\times K$ whose i^{th} row is x_i and also unbiased unconditionally if $E[\hat{\beta}]$ exists.

We have a sample of U.S. universities over the five year period 1998 to 2002 and the data is aggregated at the university level. Even though some universities are recurrently observed during this time period, we do not perform panel data analysis but rather we compute the annual averages of the time varying variables (both dependent and explanatory variables) over the sample period. This approach is also adopted in Siegel, Waldman and Link (2003). The main reason for this modeling choice is to maximize the observation number to better rely on asymptotic results in the cross section dimension. Given that a license produces a stream of revenues over time, it is expected that the annual level of total returns will depend on the previous years' levels, and thus, any panel data analysis would need to take lags of the dependent variable into account, and modeling about the lag structure may require a longer stream of data than we have here. Moreover, introducing such a lag structure may lead to sample selection problems as non-recurrent respondents would be dropped from the regression. By working with the annual averages of the variables on the cross section dimension, we can obtain the largest possible size of sample, which initially includes 180 U.S. universities. Finally, we assume that we have a random sample of outcomes for these universities.

Even though Assumption 1.b is stronger than Assumption 1.a, it is not as strong as assuming that the disturbance term and the explanatory variables are independent, therefore, it still leaves the variance of the disturbance term conditioned on the regressors, denoted with $V[u \mid x]$, as unrestricted. Given the observed skewness in the licensing rent data, we can not assume that errors are normally distributed. Together with a fairly large sample of observations that we have here for cross-section of universities, there is no additional gain from making some form of homoskedasticity assumption for the disturbance term in equation (2). For inference, we rely on asymptotic results, which are obtained by increasing the sample size in the cross section dimension. For any possibility of heteroskedasticity, we use and report the heteroskedasticity consistent standard errors.[7] The Wald test statistics based on these standard errors are asymptotically distributed χ^2 with the appropriate degrees of freedom depending on the number of restrictions tested (Wooldridge, 2002) and the reported p-values below are from this distribution.

6. Results

We present the OLS estimation results for various models (Models 1 to 7) in Table 6. For the descriptions of variables' names in these models, and the summary statistics for the variables used in the estimations, we refer the reader to Tables 3 and 4, respectively. Table 5 also presents the correlations among the variables. In the following, we discuss the results for the models in Table 6. In conclusion, we take Model 3 as the base model.

We start with Model 1 in Table 6, where we include all the explanatory variables except *FL dummy* we consider in Table 3. The model explains the 30% of the variation in licensing rent. The university specific variables (*quality*, *size*, *med*, and *private*) are positively related with the licensing

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[7] The heteroskedasticity-robust standard errors are obtained by a SAS procedure.

rent as expected. The variable *quality* stands out among these variables with a p-value of 14%. The contract variables (*exclusive*, *small*, and *start-up*) are negatively related with the licensing rent. The other TTO variable *age* has a negative sign. All explanatory variables except *exclusive* are insignificant at the 10% level.

Given the performance of Model 1, we suspect that Florida State University is an outlier among the big winner universities compared to its characteristics. Other than the fact that it has medical school, it is a public university with relatively low number of citations per faculty (246), total research expenditures ($135,800,000) slightly higher than median level and a relatively recent TTO (7 years of experience), etc (see also Table 4 for the comparison). We separate this observation by introducing a dummy variable, *FL dummy*, which takes the value of one for the Florida State University and zero otherwise. We add this dummy variable to the variables in Model 1 and obtain Model 2. The dummy variable turns out to be significant at the 0.1 percent level and its coefficient yields nearly the licensing rent for this university. The fitting performance of the new model is better as the R^2 and $\bar{R}^2$ significantly increase to 44% and 39%, respectively. The economic impact of medical school dummy is now lower, whereas that of private university dummy is higher. The coefficients of other variables are slightly affected with the introduction of the dummy. Because separating the observation for Florida State University appears to be useful in terms of predictions of the model for other universities, we continue to do so in the rest of our analysis.

From Model 2, we observe that the variables *age* and *stateR&D* are highly insignificant with p-values of 87% and 52%, respectively. We drop these variables and obtain Model 3. The magnitudes of coefficients and significance of the remaining variables are slightly affected and $\bar{R}^2$ are slightly higher. Particularly, the *quality* variable is now significant at the 10% level and the variable *exclusive* is border line case at the same level. Although other variables are not significant at the standard levels, they are not too insignificant, either. The signs of their coefficients are as expected and they provide important economic information so we prefer to include them. Therefore, we take Model 3 as the base model. Nevertheless, Models 4, 5 and 6 show the possible effects of excluding these variables. In Model 4 the variables, *med* and *private* are further excluded from Model 3. Model 5 is obtained by excluding the contract variables (*exclusive*, *small*, and *start-up*) from Model 3. In Model 6, both groups of variables are excluded from Model 3. Note that one fails to reject these restrictions in Model 3 at the standard levels of significance.[8] Nevertheless, R^2 and $\bar{R}^2$ s among these models are very close, therefore, we choose the most informative one, which is Model 3. Furthermore, Model 7 is presented to demonstrate the impact of the *quality* variable by leaving this variable out from Model 2. The variables *med*, *private*, *age*, *exclusive*, and *stateR&D* become either significant or have p-values that are around the 10% level. Particularly, the variable *size* is significant at the 0.01% level. In essence, the *quality* variable replaces the effects of these variables in Model 2.

In the base model (Model 3), R^2 and $\bar{R}^2$ are 43% and 40%, respectively. The impact of a single citation received on the licensing rent is $7,666. The coefficient of the variable *size* can be interpreted as the "rate of return" from total research expenditures and slightly exceeds 1 cent for each dollar of research expenditures. The variables *med* and *private* show that private universities and the universities with medical school have additional advantage in generating license rent (around $1 Million and $1.5 Million, respectively) albeit these effects are statistically insignificant at the standard levels due to co-presence of the variables, *quality* and *size*. The contract variables (*exclusive*, *small*, and *start-up*) are still negatively related with the licensing rent. Particularly, increasing the share of total licenses that are licensed exclusively 1 percentage point decreases the licensing rent nearly $48,318. The other contract variables also have similar impacts and can be similarly interpreted although they are less statistically significant.

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[8] For the tests, the Wald test statistics which is distributed as χ^2 with the appropriate degrees of freedom ($d.f.$) and the associated p-values (denoted with p) are calculated as follows: $\chi^2 = 2.35$, $d.f. = 2$, $p = 0.31$ for the restrictions in Model 3 yielding Model 4, $\chi^2 = 2.67$, $d.f. = 3$, $p = 0.45$ for the restrictions in Model 3 yielding Model 5, and $\chi^2 = 4.23$, $d.f. = 5$, $p = 0.52$ for the restrictions in Model 3 yielding Model 6.

Figure 4 presents the standardized residuals from Model 3, which are sorted by the ranked licensing rent. Except for the Columbia University and University of California System, the values of standardized residuals remain less than the rule of thumb value of 3. For the University of California System, the standardized residual value constitutes a border line case. Note that this university is the third in generating licensing rent. For the Columbia University, the standardized residual value is close to 10, however, this university is top ranked in terms of licensing rent and constitutes a rather extreme case. We did not expect much to explain the universities with extreme rents *per se*. The objective here is rather to use the information they provide to explain the expected value of license rents for other universities in the population. Hence, we find the performance of Model 3 in terms of values of the standardized residuals as satisfactory. Figure 5 also presents the predicted values for licensing rent together with the actual values based on Model 3.

Because we asked the question of what universities can expect in terms of rent generation from the licensing activities, we carry out a mean analysis of the predictions of licensing rent from Model 3 for various categories of the population and present the results in Table 7. We also provide a mean analysis of the explanatory variables in the same table.

The expected licensing rent is nearly $4.5 Million in the population, which is nearly the 2.5 percent of the average size of universities in terms of total research expenditures. The number of universities predicted with non-negative economic rent is 102, which is nearly 70% of the population. Private universities are obtaining economic rent nearly three times more than public universities. Having a medical school makes a difference as these universities are earning nearly five times more than those without medical school. Furthermore, given the status of universities in terms of medical school presence, the mean value of predicted licensing rents for private universities is higher compared to the public universities. Moreover, the mean value of predicted licensing rents for universities without medical school is lower than the one for universities with medical school given the type (private or public) of universities.

These findings are consistent with the performances of universities in terms of quality and size. From Table 7, the difference between the mean levels of citations per faculty (the measure of quality of faculty) across private and public universities that have the same status in terms of medical school presence is apparent as it is much higher for the former. For public universities, the medical school presence makes difference as higher mean level of citations. For private universities, those with medical school have higher mean size than those without medical school and the former has also a slightly higher mean citation value than the latter.

7. Conclusion

We have done an econometric analysis of economic rents of U.S. universities from patenting and licensing activities, which dramatically surged in the last two decades. The data is mainly from AUTM surveys on various aspects of licensing activities and some other sources on the characteristics of the universities. We also incorporate some salary data from CUPA surveys in order to estimate operating cost of TTOs. The data covers a cross section of 148 U.S. universities and is averaged over the five year period from 1998 to 2002. We consistently estimate a structural equation of licensing rent on various explanatory variables by the ordinary least squares procedure. We rely on asymptotic results in the cross section dimension for inference and use the heteroskedasticity-consistent standard errors.

We wanted to answer the question of what US universities can expect in terms of economic rent from licensing activities as the rent generation motive is one of the concerns raised in this context. We obtain that the expected licensing rent in the population corresponds to nearly 2.5% of the average size of universities in terms of research expenditures. Moreover, from Table 6, the coefficient of the variable *size* is estimated around 1,000 across models. Given the units of measurement, this means that the “rate of return” to R&D funds is about 1%. Finally, nearly 70% of the universities are predicted to obtain non-negative economic rent from these activities.

We identify the quality of faculty (which is measured by the citations per faculty received in technology departments) and (to a lesser extend) the size of the university in terms of total research expenditures as the main sources of advantage in generating licensing rent. Controlling these factors, the private universities and the universities with medical school seem to have additional advantage in terms of generating licensing rent; however these effects are not statistically significant at the standard levels. Moreover, TTO experience is found to be neither economically important nor statistically significant. Nevertheless, it appears that exclusive contracts and contracts licensed to small or start-up companies are paying off negatively in the population, which are the type of licenses that Bayh-Dole Act aimed to encourage. Finally, state level R&D intensity does not seem to be an important factor, either. Therefore, our results may suggest that universities can give priority in investing to high quality faculty and appropriating research funds in technology departments in order to be successful in generating license rent.

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Table 1: Top 20 Universities in terms of Licensing Rent

Universities	**License Rent** [a]
Columbia University	$109,586,843
Florida State University	$56,499,619
University of California System [b]	$53,963,400
Yale University	$35,264,382
Stanford University	$34,879,008
New York University	$30,461,976
Massachusetts Inst. of Technology (MIT)	$26,966,214
Michigan State University	$25,305,529
University of Florida	$22,591,317
University of Washington	$21,917,569
University of Wisconsin Madison	$17,771,161
University of Rochester	$17,306,887
Dartmouth College	$13,803,977
State University of New York	$12,039,576
Emory University	$11,545,344
University of Minnesota	$11,199,555
University of Massachusetts	$11,037,850
Harvard University	$10,745,855
University of Pennsylvania	$8,942,236
California Institute of Technology	$8,844,954

[a] Averaged over the time period 1998-2002

[b] Excluding one time settlement revenue ($200 Million) of UC system for its human growth invention in 2000, which would place UC system as the second.

Table 2: State R&D intensity for top 20 Universities

Universities	State	State R&D Share
Columbia University	New York	5.81%
Florida State University	Florida	2.03%
University of California System	California	20.94%
Yale University	Connecticut	2.05%
Stanford University	California	20.94%
New York University	New York	5.81%
Massachusetts Inst. of Technology (MIT)	Massachusetts	5.60%
Michigan State University	Michigan	7.02%
University of Florida	Florida	2.03%
University of Washington	Washington	3.99%
University of Wisconsin Madison	Wisconsin	1.19%
University of Rochester	New York	5.81%
Dartmouth College	New Hampshire	0.51%
State University of New York	New York	5.81%
Emory University	Georgia	1.28%
University of Minnesota	Minnesota	1.82%
University of Massachusetts	Massachusetts	5.60%
Harvard University	Massachusetts	5.60%
University of Pennsylvania	Pennsylvania	4.13%
California Institute of Technology	California	20.94%

Table 3: Variable Descriptions

Variable		**Description**
y	*rent*	Licensing rent in a given university. (Averaged over the sample period 1998 to 2002 and in dollars)
x_1	*quality*	Total number of citations received per faculty in technology departments in a given university. This is in level and measured in 1993.
x_2	*size*	The average total research expenditures (in hundred thousands) over the sample period 1998 to 2002.
x_3	*med*	Dummy variable: 1 if university has medical school 0 otherwise.
x_4	*private*	Dummy variable: 1 if university is private and 0 otherwise.
x_5	*age*	Age of technology transfer office (in years) of a given university by 2002.
x_6	*exclusive*	The share total licenses which are executed exclusively (Averaged over the sample period 1998 to 2002).
x_7	*small*	The share total licenses which are executed to small companies (Averaged over the sample period 1998 to 2002).
x_8	*startup*	The share total licenses which are executed to start-up companies (Averaged over the sample period 1998 to 2002).
x_9	*stateR&D*	The ratio of total R&D performance level in a given state to the national R&D performance level (Averaged over the sample period 1998 to 2002).
x_{10}	*FL dummy*	Dummy variable for the Florida State University, which takes the value of one for this university and zero otherwise.

Table 4: Summary Statistics for Variables

Variable	**N**[a]	**Mean**	**Std. Dev.**	**Min**	**25th Pctl**[b]	**Median**	**75th Pctl**	**Max**	**Sum**
rent[c]	148	4,419,394	12,533,412	-804,724	-138,847	305,683	2,502,656	109,586,843	654,070,357
quality	148	485	519	1	152	318	643	2,691	71,833
size[d]	148	1,837	2,247	97	558	1,169	2,384	20,792	271,877
med	148	0.622	0.487	0	0	1	1	1	92
private	148	0.297	0.459	0	0	0	1	1	44
age	148	16.3	11.4	1	9	15	19	78	2413
exclusive	148	0.66	0.22	0.09	0.49	0.67	0.83	1.00	97.56
small	148	0.48	0.17	0.00	0.38	0.50	0.57	1.00	71.53
start-up	148	0.18	0.13	0.00	0.09	0.15	0.25	0.63	27.13
stateR&D	148	0.031	0.036	0.0003	0.0082	0.0209	0.0512	0.2094	4.6607

[a] Number of Observations;

[b] Percentile

[c] Excluding one time settlement revenue (200 Million $) of UC system related to its human growth hormone invention in 2000.

[d] In hundred thousands.

Table 5: Pearson Correlation Coefficients[a]

	rent	*quality*	*size*	*med*	*private*	*age*	*exclusive*	*small*	*start-up*	*stateR&D*
rent	1.000	0.513	0.448	0.202	0.199	0.215	-0.29	-0.07	-0.09	0.322
quality		1.000	0.682	0.249	0.371	0.462	-0.37	-0.06	-0.10	0.546
size			1.000	0.231	0.066	0.378	-0.28	0.06	-0.13	0.458
med				1.000	0.172	0.033	-0.10	0.07	-0.09	0.106
private					1.000	0.117	-0.14	-0.11	-0.03	0.280
age						1.000	-0.23	0.06	-0.14	0.157
exclusive							1.00	0.04	0.33	-0.17
small								1.00	-0.49	0.05
start-up									1.00	-0.03
stateR&D										1.00

[a] Number of observations are 148 for all variables.

Table 6: OLS Results: (Dependent Variable: *rent* ; N=148)[a]

Expl. Varbls	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
intercept	\$4,394,964 (5,399,196) 0.416	\$4,841,673 (5,394,052) 0.369	\$4,583,045 (4,987,075) 0.358	\$5,440,550 5,366,414 0.311	-\$3,239,839 1,084,707 0.003	-\$2,531,387 (918,249) 0.0058	\$6,495,566 (6,467,274) 0.315
quality	\$7,323 (4,981) 0.142	\$7,262 (4,969) 0.144	\$7,666 (4,317) 0.076	\$8,662 4,428 0.051	\$8,725 4,972 0.079	\$9,826 (5,166) 0.0571	
size	\$1,043 (859) 0.225	\$1,058 (868) 0.223	\$1,114 (950) 0.241	\$1,024 927 0.270	\$1,093 951 0.251	\$984 (938) 0.2941	\$1,792 (486) 0.000
med	\$1,709,408 (1,122,806) 0.128	\$993,913 (885,052) 0.261	\$929,676 (902,091) 0.303		\$819,825 862,727 0.342		\$1,563,912 (1,035,513) 0.131
private	\$841,298 (1,488,019) 0.572	\$1,352,546 (1,402,110) 0.335	\$1,580,170 (1,335,517) 0.237		\$1,796,721 1,428,922 0.209		\$3,122,192 (1,954,561) 0.110
age	-\$34,650 (66,307) 0.601	-\$9,750 (59,655) 0.870					\$59,876 (35,786) 0.094
exclusive	-\$5,299,445 (3,073,174) 0.085	-\$4,923,180 (3,049,916) 0.107	-\$4,868,054 (2,997,969) 0.104	-\$4,831,812 3,010,417 0.109			-\$7,005,682 (4,215,904) 0.097
small	-\$5,452,460 (6,183,001) 0.378	-\$7,199,127 (5,982,590) 0.229	-\$6,743,755 (6,256,258) 0.281	-\$6,903,048 6,307,239 0.274			-\$9,033,004 (7,047,006) 0.200
start-up	-\$3,179,954 (5,748,311) 0.580	-\$5,354,923 (5,410,534) 0.322	-\$4,851,219 (5,447,470) 0.373	-\$5,257,415 5,568,096 0.345			-\$5,257,917 (5,566,057) 0.345
State R&D	\$16,429,141 (27,882,300) 0.556	\$18,309,152 (28,132,955) 0.515					\$42,050,501 (27,747,701) 0.130
FL dummy		\$55,979,509 (817,398) <.0001	\$56,016,128 (950,143) <.0001	\$56,124,058 955,834 <.0001	\$55,289,521 646,750 <.0001	\$55,277,105 (461,923) <.0001	\$56,086,016 (874,926) <.0001
SSR	1.610E+16	1.304E+16	1.309E+16	1.32E+16	1.35E+16	1.36E+16	1.373E+16
R^2 ($\bar{R}^2$)	0.30 (0.26)	0.44 (0.39)	0.43 (0.40)	0.43 (0.41)	0.42 (0.40)	0.41 (0.40)	0.41 (0.37)

[a] Heteroskedasticity-consistent standard errors are reported in brackets. The probability values (p-values) for the estimates are from Chi-square distribution and reported under the standard errors.

Table 7: Mean Analysis

		Predicted licensing rent[b]	Quality of the faculty	Size of the university[c]
U.S. universities	N[a]	Mean	Mean	Mean
All	148	$4,419,394	485	1,837
With medical school	92	$6,384,831	586	2,240
Without medical school	56	$1,190,463	320	1,175
Private	44	$8,236,571	780	2,064
Public	104	$2,804,435	361	1,741
Private with medical school	33	$9,051,632	794	2,261
Public with medical school	59	$4,893,231	469	2,228
Private without medical school	11	$5,791,389	740	1,474
Public without medical school	45	$65,792	218	1,102

[a] Number of Observations
[b] Based on Model 3 in Table 6
[c] In hundred thousands.

Figure 1: Net Licensing Revenue
(Averaged over the time period 1998 to 2002)

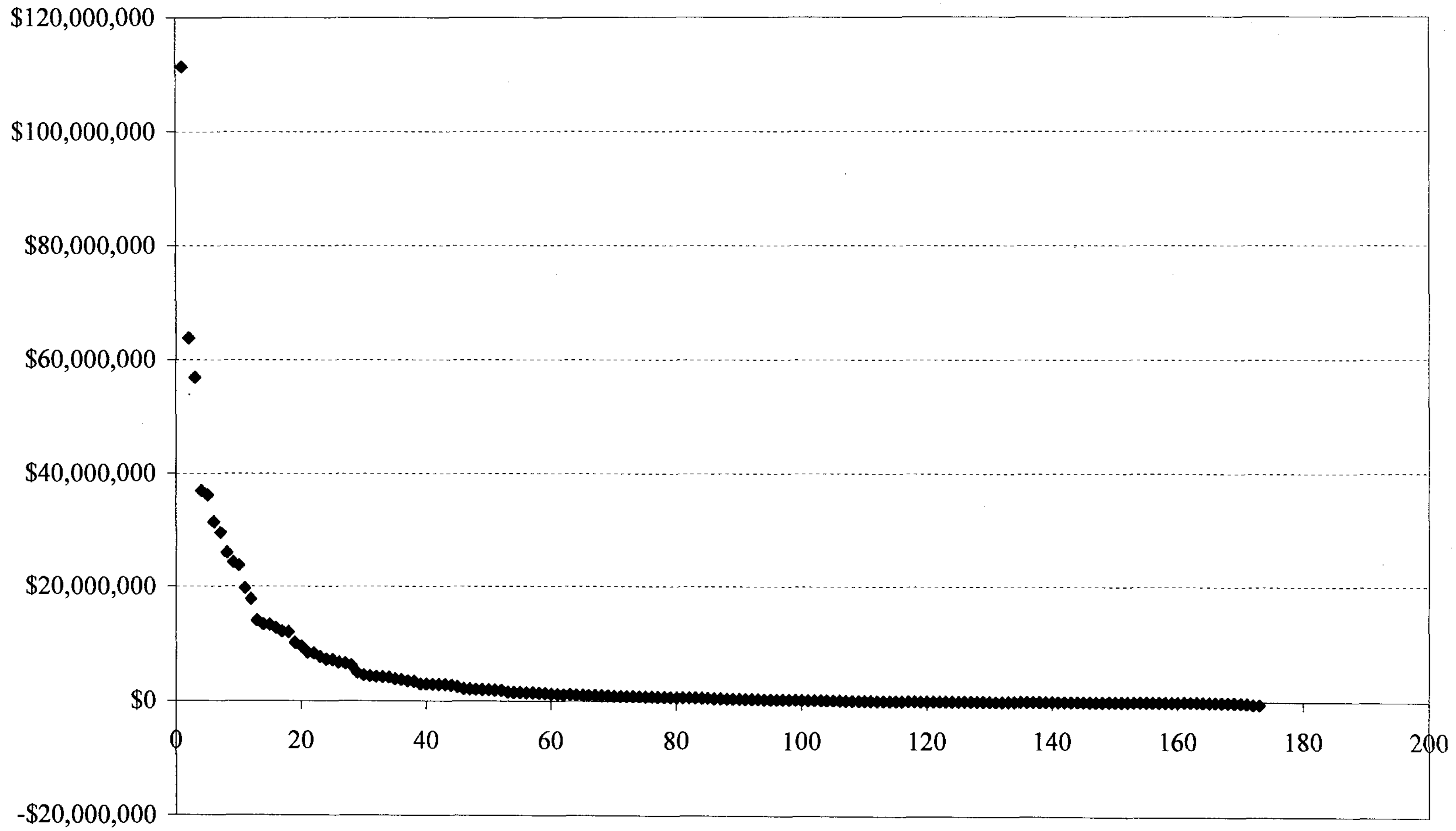


Figure 2: Net Licensing Revenue Normalized by Total Research Expenditures (Averaged over the time period 1998 to 2002)

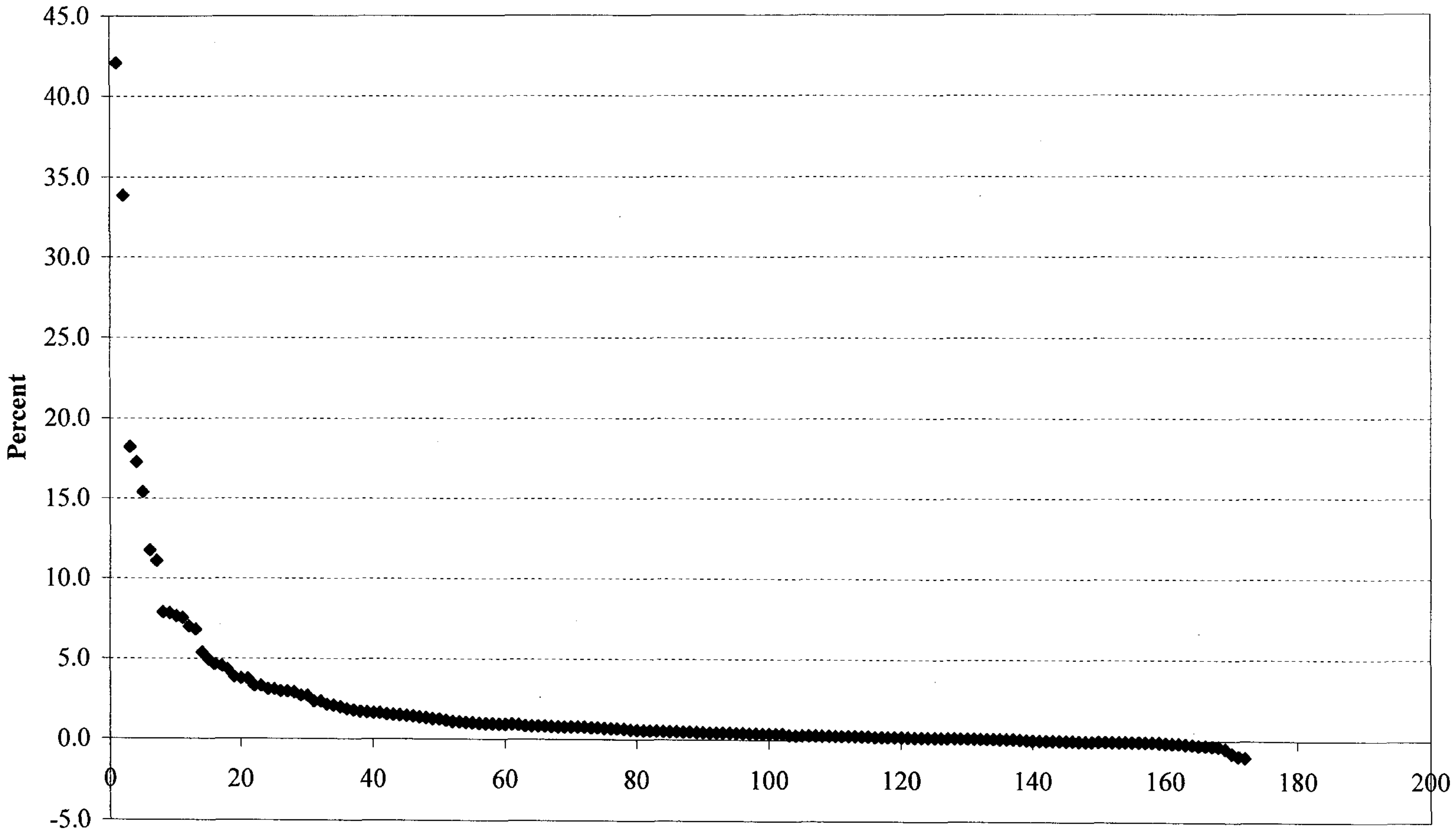
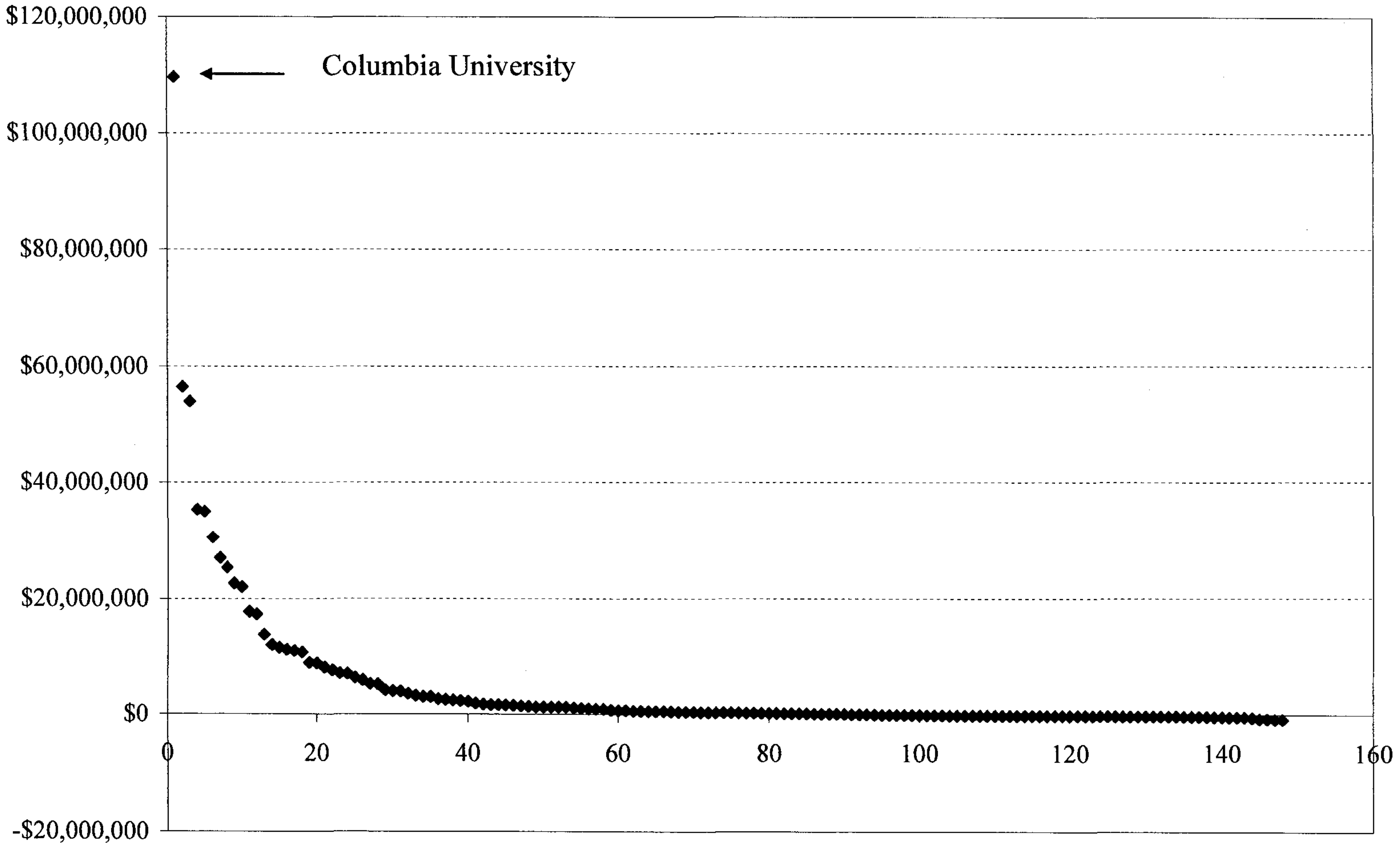


Figure 3: Ranked Licensing Rent



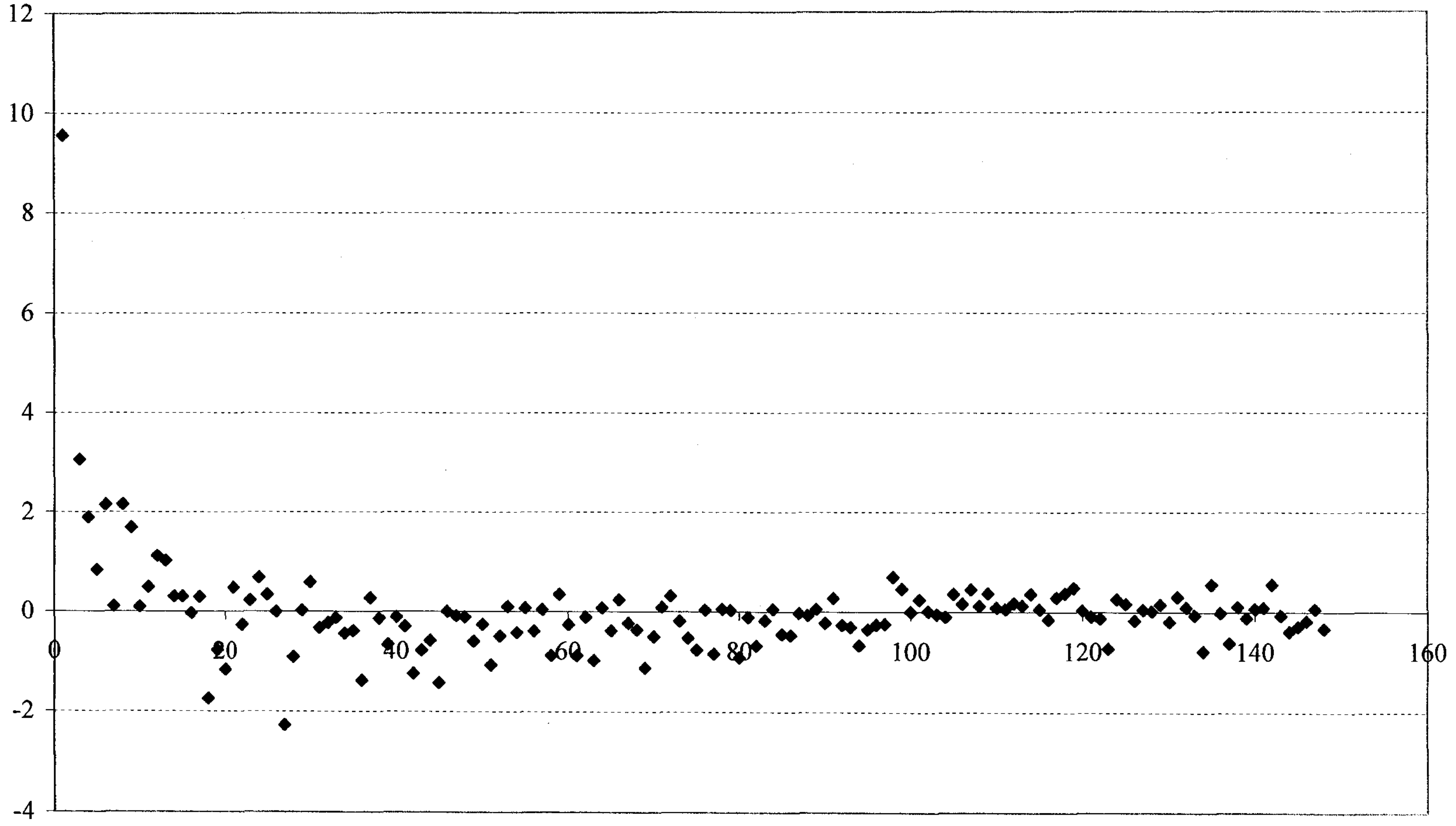
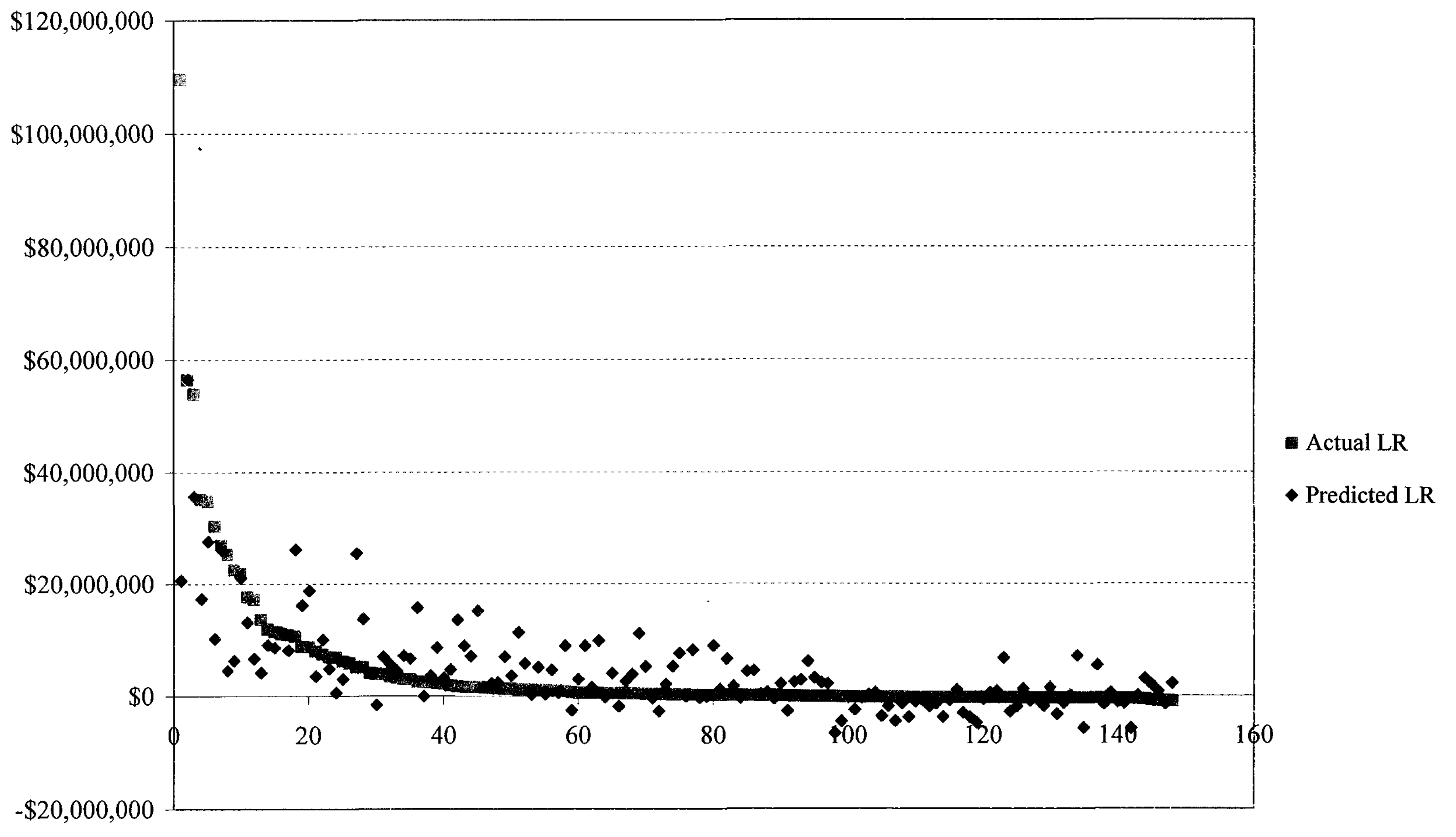


Figure 4: Standardized Residuals
(Based on Model 3 in Table 6 and Sorted by the Ranked Licensing Rent)

Figure 5: Predicted Licensing Rent (LR)
(Based on Model 3 in Table 6 and Sorted by the Ranked Licensing Rent)



9. Appendix

9.1. The operating cost of technology transfer offices (TTOs)

We want to estimate the operating cost of TTOs, which includes salary expenses and benefits for TTO staff and overhead. We have data on the employment, which comes from AUTM surveys and partial data on the salaries, which are from College and University Professional Association (CUPA) administrative compensation surveys. Below, we discuss our procedure to estimate the operating cost of TTOs and compare our calculations with real figures for a sample of universities.

AUTM surveys report the number of licensing and other full-time equivalents (FTEs) employed in the TTOs for the time period 1998 to 2002. Licensing FTEs typically include the licensing manager (also called associate director or program director) and senior and/or regular licensing associates (also called program coordinators). The other FTEs include the executive director of the TTO and other administrative and support personnel.

College and University Professional Association (CUPA) administrative compensation surveys provide data for the salaries of two key positions in the TTOs, Chief Technology Transfer Officer (CTTO) and Senior Technology Licensing Officer (STLO) over the sample period 1998 to 2002. We present the original data in Tables A.5 through A.9. Based on definitions provided for these positions in CUPA surveys, we think that CTTO and STLO correspond to the executive director and licensing manager, respectively in a typical TTO staff. [1] Regarding the salaries of remaining TTO staff, based on informal surveys, Major (1996) has some preliminary estimates for licensing associates. Regarding the benefits for TTO staff and salaries of support personnel and overhead expenses, Trune and Goslin (1996) assumes some numbers. We think that combining this limited information with the annual data from CUPA surveys is not meaningful. Because the salaries of top management in TTO and the remaining personnel are expected to be correlated, we rather prefer to

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[1] The following definitions are provided in CUPA surveys for these positions: **Chief Technology Transfer Officer**: Senior administrative official responsible for managing technology transfer activities relating to scientific discoveries and inventions. Participates in the setting and interpretation of policy pertaining to these activities and supervises the licensing and administrative staff engaged in them. Has the budgetary authority for the activities. Communicates information about the activities to the institution's senior administration or governing board. **Senior Technology Licensing Officer**: Senior administrative official responsible for managing licensing projects and cases, including identifying and evaluating technologies with commercial potential and licensees for the technologies. Prepares invention summaries for marketing purposes and develops and implements marketing strategies for each technology. Drafts and negotiates licenses and other types of agreements, including material transfer, collaboration, and nondisclosure agreements.

use available data for the former in CUPA surveys to obtain estimates for the latter as follows: Based on the itemized expenses for TTO accounts of the Iowa State University and University of Minnesota, we make the following assumptions: For the salary of remaining licensing staff (typically senior and/or regular licensing associates), we take one half of the CTTO 's salary on average. For the salary of support staff (typically senior and/or regular accountant, secretary, etc), we take one third of the CTTO's salary on average. Moreover, we take 30% and 25% of total salary expenses for the employee benefits and overhead expenses, respectively on average.

CUPA surveys provide data on median salaries for all doctorate universities of a given sample and also for the sub samples of these universities based on budget quartiles. For the latter, the sample of universities in a given year are ranked in terms of their operational budgets from low to high and one quarter of universities are included in each quartile. Then, median salary for each quartile is reported. One can find the budget ranges for each quartile in Tables 20 to 24 depending on the year. We would like to use the median salaries specific to budget quartiles rather than the ones for the entire sample in order to better approximate the operating expenses of TTOs for individual universities. However, we can not assign the median salaries above to universities based on their operational budgets because the data on operational budgets are not available for all universities during the time period that we are interested in. Particularly, CUPA Surveys do not report the budget figures for the individual universities within their samples. Nevertheless, AUTM surveys report the total research expenditures of universities. Because the total research expenditures and operational budget expenditures can be presumed to be positively correlated, (which should be especially true for the sample of doctorate universities in CUPA surveys), we assign the median salaries to universities based on their total research expenditures.

In a given year, we rank the sample of universities in AUTM survey in terms of their total research expenditures from low to high and then find the 25th , 50th and 75th percentiles, which form the basis for the quartile ranges.[2] Then, we assign the median salaries for each quartile from CUPA surveys.[3] This is equivalent to the assumption that a particular university belongs to the same quartile in terms of operational budgets and total research expenditures. We checked that this assumption is valid for a large number of universities in the sample and present Iowa State University (ISU) and

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[2] For example, the 25th , 50th and 75th percentiles turn out to be approximately $53 Million, $127 Million and $285 Million, respectively in year 2002. Then, the first quartile of universities includes those universities with total research expenditures approximately less than $53 Million, and the second quartile includes those universities with total research expenditures that are approximately between $53 Million and $127 Million. The remaining quartiles are similarly defined.

[3] Note that the overwhelming majority of the universities in our sample are doctorate institutions.

University of Maryland at College Park as examples in Table A.1. However, for a few border cases such as North Carolina State University and University of Akron presented in the same table, we may end up using the median figures from immediately adjacent quartile.

To sum up, the operating cost of a TTO in a given university i which belongs to quartile j where $j=1,2,3,4$ in terms of total research expenditures (and in terms of operational budget, too by assumption) in a given year t where $t=1998,1999,2000,2001,2002$ and employs $n\geq 1$ licensing FTEs and $m\geq 1$ other FTEs is

$$C_{it}=TS_{it}+B_{it}+H_{it} \tag{A.1}$$

where TS_{it} denotes the total salary expense and B_{it} denotes the benefits for TTO staff and H_{it} denotes the overhead expense, which are assumed to be related as

$$B_{it}=0.3*TS_{it} \tag{A.2}$$

$$H_{it}=0.25*TS_{it} \tag{A.3}$$

Total salary expense for TTO staff has two components

$$TS_{it}=LS_{it}+OS_{it} \tag{A.4}$$

where LS_{it} denotes the salary expense for licensing FTEs and OS_{it} denotes the salary expense for other FTEs in TTO, which are in turn calculated as

$$LS_{it}=S_{2,jt}+(n-1)*\left(S_{1,jt}/2\right) \tag{A.5}$$

$$OS_{it}=S_{1,jt}+(m-1)*\left(S_{1,jt}/3\right) \tag{A.6}$$

where $S_{1,jt}$ and $S_{2,jt}$ denotes the salary of CTTO and STLO, respectively for quartile j in a given year t from CUPA surveys. Note that when $n=1$ and/or $m=1$, we assume that TTO employs the corresponding top management only.

Note that for the case of the University of California (UC) System, which includes 9 campuses and the office of the president, AUTM surveys report the employment figures for the entire system rather than individual campuses. For this exceptional case, calculations are done by assigning top management to each campus and the office of the president, that is, the formulas in (A.5) and (A.6) become

$$LS_{it} = 10 * S_{2,jt} + (n-10) * \left(S_{1,jt}/2\right)$$

$$OS_{it} = 10 * S_{1,jt} + (m-10) * \left(S_{1,jt}/3\right)$$

where $n > 10$ and $m > 10$ as one can verify from column 4 in Table A.3.

We compare our estimates with the actual numbers for the University of Minnesota, University of California (UC) System and Iowa State University (ISU) in Tables A.2 to A.4, respectively:

One can verify from Table A.2 that estimated numbers for University of Minnesota are pretty close to the actual ones. Given the exceptional size of the TTO in the UC system, the estimated numbers could come close only so much (see Table A.3). Regarding the ISU, there is a apparent discrepancy between the actual and the estimated numbers (compare columns 3 and 5 in Table A.4), which is in fact due to the variety of reasons: First, the number of employees with TTO under the ISU Budget book (which is also the basis for the Annual Report of Iowa State University Research Foundation, Inc. (ISURF)) and AUTM surveys are different (compare columns 2 and 4 in Table A.4). Furthermore, the base salaries for some employers are much higher than the department salaries in the Budget Book, and it is the latter that is taken into account in the calculations of the Annual Report and the Budget Book. Moreover, from Table A.2 in year 2000, University of Minnesota has 13 FTEs employed in its TTO, which is 1 FTE less than ISU from column 4 in Table A.4, whereas the actual cost for TTO of ISU is dramatically lower. However, the estimates for the operating expenses of TTOs of both universities at that year are pretty close, which is consistent with the similar sizes of both TTOs. The bottom line is once the employment figures reported in AUTM surveys and the base salaries reported in the Budget Book are taken into account, the estimated numbers for the TTO of ISU are reasonable.

From Tables A.2 to A.4, one can also observe that the estimated total cost for TTOs is monotonic in the size of TTO employment reported in AUTM surveys, therefore, it reflects the operating expenses of TTOs qualitatively well.

Table A.1
Quartiles
Fiscal Year 2002

Universities	Total Operational Budget [a]	Total Research Expenditures [b]	Quartile in terms of budgets [c]	Quartile in terms of total research expenditures [d]
Iowa State Univ. [e]	$695,792,000	$212,100,000	3	3
Univ. of Maryland at College Park [f]	$938,145,312	$352,378,665	4	4
North Carolina State University [g]	$725,588,000	$478,613,713	3	4
The Univ. of Akron [h]	$269,997,782	$17,853,485	2	1[i]

[a] CUPA Surveys roughly define budget as total institutional budget including research funds, student aid, and auxiliary enterprises but excluding capital funds. Based on this definition, we exclude the expense item, Operations and Maintenance of Plant from operational budget figures of individual universities presented in this table.

[b] Source: AUTM Survey Fiscal Year 2002

[c] These quartiles ranges are based on CUPA surveys. See Table 9 for year 2002.

[d] See footnote 9 for the quartile ranges.

[e] Office of Controller.

[f] Source: Department of Budget and Fiscal Analysis.

[g] North Carolina State University Annual Financial Report 2002.

[h] Annual Financial Report 2002.

[i] The data for the first quartile is not available for this year in Table 24. We used the data from the second quartile as it is better approximation than the median figure for the entire sample, which turns out to be the right number based on budget figures.

Table A.2

Operating Expenses for TTO of University of Minnesota

Fiscal Year	Actual Operating Expenses [a]	Estimated Operating Expenses	Total number of FTEs reported to AUTM Survey
2000	$1,137,813	$1,147,240	13
2001	$1,463,561	$1,630,376	18
2002	$1,711,215	$2,069,411	23

[a] Excluding the expense item consultant/purchased person, which is a sizable component of the total operating cost of the TTO in the University of Minnesota.

Table A.3

Operating Expenses for TTO of University of California System

Fiscal Year	Actual Operating Expenses	Estimated Operating Expenses	Total number of FTEs [a]
1998	$7,913,000	$7,761,309	97 =38+59
1999	$8,476,000	$7,697,755	92 =35+57
2000	$9,677,000	$9,056,158	105=41+64
2001	$10,832,000	$10,008,097	110=45+65
2002	$12,135,000	$13,277,207	140=62+78

[a] Source: AUTM Surveys. (Licensing FTEs + Other FTEs, respectively)

Table A.4

Operating Expenses for TTO of Iowa State University

Year	Total number of employees under TTO in the ISU Budget Book	Actual operating cost reported	Total number of FTEs reported to AUTM	Estimated Total Cost
1998	9	$362,970 [a]	10.75	$818,881
1999	10	$437,243 [a]	14	$1,009,981
2000	10	$537,796 [a]	14	$1,102,531
2001	10	$500,050 [b]	13	$996,117
2002	10	$541,029 [b]	14	$1,157,718

[a] Source: Annual Reports for the years 1998-1999 and 1999-2000 Iowa State University Research Foundation, Inc. (ISURF)

[b] Source: ISU Budget Book. Note that the Budget Book leaves out an expense item (administrative and other) reported in the Annual Report, which is around $50,000 in previous years.

Table A.5

Salary Data 1998

	Position	Median Salaries ($) (1998-1999)	Number of observations
All Doctorate Institutions	CTTO	100,874	40
	STLO	63,314	24
Doctorate Institutions with Operational Budgets (Million $) ≤ 179.5	CTTO	NA[1]	
	STLO	NA	
$[179.5, 324.3]$	CTTO	80,510	5
	STLO	NA	
$[324.3, 594.9]$	CTTO	101,860	15
	STLO	69,940	9
≥ 594.9	CTTO	108,528	17
	STLO	63,000	11

Source: CUPA (1999); CTTO and STLO stand for Chief Technology Transfer Officer and Senior Technology Licensing Officer, respectively.

Table A.6

Salary Data 1999

	Position	Median Salaries ($) (1999-2000)	Number of observations
All Doctorate Institutions	CTTO	102,689	55
	STLO	70,050	26
Doctorate Institutions with Operational Budgets (Million $) ≤ 178.7	CTTO	69,533	6
	STLO	73,450	4
$[178.7, 325.3]$	CTTO	82,523	7
	STLO		2
$[325.3, 661.7]$	CTTO	106,256	18
	STLO	76,047	8
≥ 661.7	CTTO	112,258	24
	STLO	68,178	12

Source: CUPA (2000); CTTO and STLO stand for Chief Technology Transfer Officer and Senior Technology Licensing Officer, respectively.

Table A.7

Salary Data 2000

	Position	Median Salaries ($) (2000-2001)	Number of observations
All Doctorate Institutions	CTTO	110,470	63
	STLO	75,677	33
Doctorate Institutions with Operational Budgets (Million $) ≤ 184	CTTO	70,700	7
	STLO		2
$[184, 337.7]$	CTTO	93,265	9
	STLO	82,000	5
$[337.7, 705.6]$	CTTO	111,295	20
	STLO	85,276	9
≥ 705.6	CTTO	118,395	26
	STLO	69,250	16

Source: CUPA (2001); CTTO and STLO stand for Chief Technology Transfer Officer and Senior Technology Licensing Officer, respectively.

Table A.8

Salary Data 2001

	Position	Median Salaries (2001-2002)	Number of observations
All Doctorate Institutions	CTTO STLO	114,281 79,258	59 36
Doctorate Institutions with Operational Budgets (Million $) ≤ 187	CTTO STLO	70,700 NA	5
$[187,353]$	CTTO STLO	98,133 66,550	8 5
$[353,689.5]$	CTTO STLO	104,910 83,136	17 14
≥ 689.5	CTTO STLO	124,976 72,877	29 17

Source: CUPA (2002); CTTO and STLO stand for Chief Technology Transfer Officer and Senior Technology Licensing Officer, respectively.

Table A.9

Salary Data 2002

	Position	Median Salaries ($) (2002-2003)	Number of observations
All Doctorate Institutions	CTTO STLO	126,072 83,954	66 42
Doctorate Institutions with Operational Budgets (Million $) ≤ 192.9	CTTO STLO	NA[1] NA	
$[192.9, 385.5]$	CTTO STLO	113,850 62,205	11 6
$[385.5, 743.9]$	CTTO STLO	110,000 86,915	24 16
≥ 743.9	CTTO STLO	131,700 83,954	31 20

[1] Not available. Source: CUPA (2003). CTTO and STLO stand for Chief Technology Transfer Officer and Senior Technology Licensing Officer, respectively.

CHAPTER 5. GENERAL CONCLUSION

1. Conclusion

We have identified three specific problems in the economics of innovation and addressed each of them in separate essays in this thesis. Although the essays are self contained, they are inter-related as each one refers to various stages of the overall innovation process, which typically involves R&D stage, intellectual property (IP) choices, commercialization and market competition, adoption and diffusion stages.

Essay 1 (Chapter 2) starts from the R&D stage of the innovation process as we revisit the problem of correlation choices in Dasgupta and Maskin (1987). We integrate the intellectual property choices stage into their framework by taking into account the fact that firms have the option of trade secrecy in addition to patents in protecting their inventions, and ask whether this would have any impact on firms' diversification efforts. Essay 2 (Chapter 3) refers to the adoption and diffusion stages of the innovation process as we look at the economic effects of the introduction of Genetically Modified (GM) food in the European Union (EU) agricultural and food system. The third essay refers to R&D, IP choices and commercialization stages. After the Bayh-Dole Act of 1980, universities can more easily patent and license their inventions. The inventions can be licensed to companies for further development, which in turn pays off to the university typically in the form of royalties. We want to analyze the determinants of the licensing rent generated from these activities.

We approach these three problems with different methodologies. Essay 1 is theoretical in nature and we use a game-theoretic modeling of firms' project and IP choices in an R&D race. In essay 2, we use a partial equilibrium modeling of European agro food sector. Then, we calibrate the model's parameters by using the available data in year 2000. Essay 3 is empirical in nature and based on econometric modeling, where we estimate a structural equation of licensing rents of universities.

Therefore, this thesis is methodologically diversified in analyzing the problems in the economics of innovation.

These three essays also point out the role of government to influence the innovation process in various contexts. In essay 1, we obtain that government can induce the competitive diversification efforts of private firms in a market setting only when multiple IP instruments are present, particularly, by weakening the patent protection relative to trade secrecy protection, which can be obtained by decreasing the patent length or strengthening the trade secrecy protection, respectively. In essay 2, we study the economic implications of the EU's complex and (ongoing) regulation of authorized GM products, which aims to provide a choice to consumers between GM and non-GM products. The regulation implies significant economic costs because it requires labeling and traceability of GM content in all stages of production, and allows only a stringent adventitious presence of GM content in other products. We obtain that the labelling and traceability requirements of GM products, which discourage the production of GM food, further decrease aggregate welfare.

In the third essay, the main impact of the government is through the Bayh-Dole Act of 1980, which allows U.S. universities and non-profit organizations to retain title to patents deriving from federally funded research. The main presumption of the Act was that exclusive licensing is often necessary as an incentive to develop university inventions that requires significant amount of fixed investment. Since the Act, U.S. universities are actively involved in technology transfer and licensing activities. This growth in university patenting and licensing activities has resulted in a considerable debate on how these activities have affected the traditional role of universities (advancement of science and dissemination of knowledge) and on whether the Bayh-Dole Act was in fact necessary to promote technology transfer.

Finally, we finish up by reviewing main results from these three essays below.

In Essay 1, we find that the availability of trade secrets in addition to patents can induce firms to diversify further at the equilibrium towards the social optimum. The reader is referred to Proposition

2 in Chapter 2 for this result. This is interesting because the correlation problem in a market setting can be overestimated if one considers a generic R&D race with an implicit single mode of protection, which is typically thought as patent. It also points out that market can come up with smart tools or institutional features in order to solve problems that are inherent in R&D races.

In Essay 2, we find that the introduction of GM food in European agricultural and food system reduces the overall social welfare (both consumers and producers become worse off) but organic food producers may become better off. The reader is referred to Table 2 in Chapter 3 for this result. This conclusion differs from those of existing empirical studies, which have found a positive welfare impact of the new GM technology (e.g., Falck-Zepeda, Traxler, and Nelson, 2000; Moschini, Lapan, and Sobolevsky, 2000; Demont and Tollens, 2004), but it is in keeping with the analyses of Lapan and Moschini (2004) and Fulton and Giannakas (2004). Those found positive welfare effects mainly did not take into account the segregation costs to provide non-GM goods and did not allow for differentiated consumer preferences over non-GM products.

In Essay 3, we find that the main determinants of the licensing rents of U.S. universities as the quality of faculty (measured by the citations per faculty in technology departments) and to a lesser degree, the size of the university in terms of total research expenditures. The reader is suggested to compare Models 2 to 7 in Table 6 of Chapter 4 for this result. This is interesting because the *quality* variable is a good summary statistics for the various effects that would be usually thought of as critical such as the experience of TTO, state R&D intensity, medical school and private universities dummies by making them statistically insignificant at the standard levels once they are included together. This finding may suggest that universities can give priority in investing to high-quality faculty and appropriating research funds in technology departments in order to be successful in generating license rent.

2. References (for General Conclusion)

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