Intellectual Property Rights, International Trade and Plant Breeding

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1 Introduction

1.1 Background

1.1.1 Improved plant varieties as an economic good

Seed is one of the most important inputs in agricultural crop production.[1] The genetic code of seed sets the potential frontier of production, in terms of quantity and quality. The knowledgeable use of all other inputs, including land, labour, capital, fertilizers and pesticides, will determine how much of the potential embodied by the seed is realised. Seed has been produced on-farm since almost the beginning of agriculture, with farmers selecting and maintaining seeds of their crops for sowing next season and exchange with other farmers. Observing differences among plants and experimenting with crossing, together with adaptation to various environments led to the development of different varieties or races within each agricultural crop species. The emergence of modern plant breeding in the late nineteenth and early twentieth centuries applied the then-new knowledge of the field of hereditary genetics to the process of crossing and selecting among progeny. During the last 30 years, this has been boosted by yet further advances in genetics and modern biotechnology, which has increased both the range of crosses that can be made, such as the introduction of genes from one species into another, as well as the precision with which this done (i.e. at a genetic level). With the increase in scientific knowledge and the commercialisation of agriculture, plant breeding has become a specialized task that is no longer vertically integrated in farm operations in most parts of the world.

The innovative process in plant breeding consists of developing new varieties of crop species that exhibit characteristics which are of interest to either farmers (for example pest resistance, higher yield potential) or to consumers (for example, enhanced flavours, colours, or preservation qualities, or new forms such as in ornamental plants). In this respect, the breeding of new plants constitutes in some cases a process innovation for crop production, and in others, a product innovation.

Agricultural plants are self-reproducing. This rather obvious biological fact is the reason why it can be difficult for plant breeders to appropriate the results of their innovative efforts. Indeed, the very purpose to which seed is put, crop production,

[1] A more generic term is "planting material" which also covers crops species which can be reproduced vegetatively, as opposed to through seed germination, such as potatoes and roses. In this thesis, the term "seed" is used with such a broader interpretation for convenience purposes. Brush (2004) provides an overview of the management of seeds, or crop genetic resources in agricultural systems around the world and throughout time.

results in multiplication of the product. Thus, imitation of the product is fairly easy, and relatively easy to incorporate into farming operations.

A new plant variety is somewhat different from many other innovations. In terms of its characteristics as an economic good, a new plant variety is partly nonrival and excludable. The seed of a new variety can only be used by one person at a time, and thus has some of the nature of a rival good. But because a plant is self-reproducing, replicating the seed can be undertaken at very low cost, and indeed use entails replication. Thus, the seed can be considered as partly nonrival. On the other hand, it is generally possible to exclude someone from using the seed by taking measures to regulate access to the seed.

Seed is the physical embodiment of the invention of the plant breeder which consists traditionally of an iterative process of crossing existing varieties and selecting among the various progeny.[2] The pure information aspect of the invention is thus the idea of crossing certain varieties, and the resulting progeny, and insight into the possible results of this process. But the resulting variety is also partly a product of nature not necessarily influenced by the breeder. Having access to this information thus does not guarantee that someone else ('a person skilled in the art') will be able to reproduce the same variety. These are some of the considerations that led to the creation of separate criteria for protection for plant varieties, and to a different scope of protection, as compared to patents (Kloppenburg, 1988).

Plant varieties thus constitute a special form of innovation, and an assessment of IPR systems needs to take this into account. Breeders do have a number of means by which they can capture part of the benefits from the cultivation of their new variety, rather than these falling into to public domain. These means can be examined in terms of the different groups whose use of the variety breeders are attempting to restrict: other breeders, seed producers and farmers. The two most important strategies have traditionally been the use of hybrid technology and contracts with both seed multipliers and farmers. Contracts have been used in the past, but have gained additional prominence in the context of genetically modified crop varieties, as restrictions on use of seed by the farmer might also be required by biosafety regulations or pursued as a means to reduce potential liabilities for the seed providing company (Smyth and Phillips, 2002).

Innovation and technological change are governed by a range of institutional frameworks. This thesis concentrates on the intellectual property (IP) system, arguably one of the most important governance mechanisms influencing the evolution of technological trajectories or pathways in agricultural biotechnology. As in other areas of technology, innovation in plant breeding technology, including modern biotechnology, has catalyzed changes in the IP system, extending the system into the area of life forms. Novel products of biotechnological research have had to be accommodated by the IP system. This process of institutional change has been driven by an interaction between various actors in the system seeking to influence incremental and major

[2] In some cases, the breeder may induce mutations such as through the use of radiation. More recently, with the development of genetic modification, it has become possible to insert specific genes into plants, including from other species.

adjustments in the system to their perceived benefit (Graff and Zilberman, 2007; Brousseau, Garrouste and Raynaud, 2011). These actors include individuals and organizations involved in research and development (R&D) in agricultural biotechnology and plant breeding, in both the public sector and the private sector, as well as seed propagators, farmers, other businesses involved in the agricultural value chain, non-governmental organizations, and others. These agents of change attempt to influence the components of the IP system, in which a distinction can be made between legislators (define and create legal instruments), regulators or administrators (IP-granting authorities, who interpret and implement instruments) and the judiciary (interpret legal instruments as a result of conflicts). Thus, IP both conditions and influences innovation, and conversely, technological change drives the evolution of the IP system, by presenting new challenges and disrupting the configuration of varying and opposed interests. The challenges posed to understanding and informing governance frameworks can be placed in a longer term perspective which recognizes the historical evolution of the IP system and strategies for appropriating returns on investments made in biotechnology R&D and plant breeding.

1.1.2 Historical development of IP for plant varieties

During the 20th century, the commercialization of agricultural genetic inputs led to the creation of new IP instruments, including plant patents[3] in the US in 1930 (for asexually reproduced – or vegetatively-propagated – species, other than potatoes and edible tubers) and then the later emergence in Europe of plant varietal protection (PVP), also referred to as plant breeder's rights (PBR), in Europe. PVP was developed due to the problems in applying patent protection to this technological field. Patents are generally granted on the demonstration of novelty and an inventive step. The former is difficult to demonstrate and, concerning the latter, standard breeding methods may not constitute such an inventive step. Furthermore patent protection requires that a written description be provided that allows someone 'skilled in the art' to reproduce the invention which also presents difficulties in the case of new plant varieties which are usually based on a process of repeated crossing and selection of two or more parental varieties. The specific outcomes of each crossing are subject to random variation and thus neither predictable nor necessarily reproducible. PVP, as a new form of protection, sometimes described as a combination of copyright and patent protection (e.g. Janis and Smith, 2006), was gradually adopted by most industrialized countries. International harmonization led to the International Union for the Protection of New Varieties of Plants (UPOV[4]) in 1961.

The scope of UPOV protection, both in terms of species coverage and also the rights conferred, was extended in revisions introduced in 1978 and 1991. UPOV 1978 allowed member countries to designate which species or genera they wanted to include

[3] In this thesis, the term "patent" generally refers to utility patents; plant patents are referred to specifically.

[4] Union Internationale pour la Protection des Obtentions Végétales

for protection, while UPOV 1991 requires that all crops are included, although allowing a phased expansion of coverage. The minimum protection period has increased slightly under UPOV 1991. Although many countries operate under the UPOV 1978 Convention, any countries that now apply for membership must do so under the 1991 Convention.

Under UPOV 1978, protected varieties can be freely used in a competitor's breeding program. UPOV 1991 addresses the issue of essentially derived varieties (EDVs), where a new variety may exhibit slight (often cosmetic) differences from a protected one; in this case the owner of the original variety is entitled to share in any benefits. In contrast, a variety protected by a utility patent cannot be used in other breeding programs without permission. This is a major distinction between patents and PVP and helps explain why seed companies might prefer to use utility patents in the USA to protect their materials from competitors. Advances in molecular biology have allowed ever more sophisticated forms of reverse engineering that allow seed companies to take advantage of their competitors' varieties, including hybrids. There is increasing pressure from many larger seed companies to either strengthen UPOV's rules on the breeder's exemption or to adopt patent (or patent-like) protection (Donnenwirth, Grace and Smith, 2004). Such proposals are opposed by many smaller companies and are seen as politically unrealistic given current debates over IPRs.

Technological developments such as these in the area of biotechnology induced the introduction of utility patents in the plant breeding sector already at an earlier point in time. The most notable and earliest shifts in patent policy came in the US through a number of landmark court cases:

- *Diamond v. Chakrabarty* (1980), which involved the first utility patent on a living organism that embodied a biological invention;

- *Ex Parte Hibbard* (1985), which allowed whole plants that embodied biological inventions to be considered as patentable subject matter

- *J.E.M. Ag Supply Inc. v. Pioneer HiBred International Inc.* (1995), which confirmed that plant varieties could be eligible for utility patents, despite the availability of PVP.

PVP and patents differ with respect to those features that allow breeders to control the use of their innovations: production of the variety by competitors, use of the variety in a competitor's breeding program, and farmer seed saving and exchange. The UPOV conventions (and utility patents) provide clear protection against unauthorized commercial production of a protected variety. In addition, UPOV 1991 allows the plant breeder to control the use of harvested material if there has not been an opportunity for collecting royalties on the propagating material. (This is used, for instance, in cases where royalties can be charged on marketed flowers whose propagating material was planted in countries without operational PVP.) Table 1.1 summarizes the basic differences between the two forms of protection.

The other source of 'competition' for the plant breeder is farmers, who may save or exchange seed rather than buying a fresh supply. The three options in Table 1.1

present sharp differences. UPOV 1978 essentially addressed only commercial seed sale and did not include restrictions on seed saving or (non-commercial) seed exchange among farmers. UPOV 1991, on the other hand, prohibits any multiplication of a protected variety, but allows exceptions for specified species or varieties for farmers' use 'on their own holdings'; the exception does not extend to informal trade and exchange among farmers. Seed of varieties protected by utility patents may not be saved or exchanged.

Although other countries followed different paths in their legal evolution, the general trend has been similar to that in the US.[5] In the principal agricultural producing countries of the OECD, patent protection is at least available for components of plants, such as recombinant genes or cell lines, if not for whole plants as an organism. European countries have elected to not permit patenting of whole plants as an organism (Louwaars et al., 2009; Van Overwalle, 2008). Nevertheless, even where patent protection is not available for whole plants, such plants may effectively be protected by patent protection if they incorporate a patented component.

UPOV 1978 allowed member countries to designate which species or genera they wanted to include for protection, while UPOV 1991 requires that all crops are included, although allowing a phased expansion of coverage. The minimum protection period has increased slightly under UPOV 1991. A variety is eligible for PVP under UPOV if it is distinct, uniform and stable (DUS) and it has not been previously marketed with the consent of the breeder. For a utility patent, the variety has to be new, its characteristics must be non-obvious and useful (agriculture falls under 'industrial application') and a sample of the variety generally has to be deposited with the patent office (to meet the disclosure requirement).

The use of both PVP and patents has grown significantly over time in both the US (Pardey et al., 2012) and the EU (Louwaars et al., 2009). In the last few decades, the US witnessed a modest decline in applications for PVP titles from the late 1990s, recovering towards the end of the next decade. This period also witnessed some fluctuations and slower growth in applications for both plant patents and plant-related utility patents. On the other hand, the use of PVP in the EU has generally continued to grow through the 1990s, following on the introduction of a European Community PVP title, leading to declining use of nationally-issued titles (Louwaars et al., 2009). There is though a lack of comparable information on the issuing of plant-related patents in the EU.

Patent and PVP protection is increasingly available in emerging and developing countries. Under the Agreement on Trade Related Aspects of Intellectual Property (TRIPS) which entered into force in 1995, members of the World Trade Organization (WTO) are required to provide patent or some other form of IP protection for plant varieties, as well as patent protection for biotechnological inventions, with extensions having been provided for least developed countries.

[5] Van Overwalle (2008) provides a description of the European context which is complicated by the existence of IP regimes at both national and supranational levels. Galushko, Gray and Smyth (2010) provide a succinct summary of the evolution of Canadian IP regime concerning IP protection for plants and plant varieties, including those altered through genetic modification.

As they involve a reconfiguration of commercial practices and property rights, these changes have been the source of considerable controversy among farmers, companies, governments and other stakeholders, including NGOs.[6] This is evidenced by the legal cases mentioned above. In terms of governments and legislators, the Dutch Parliament has, for example, debated developments in IP protection in 2010 and 2011, partly because of concerns over the implications for the country's substantial private sector presence in plant breeding (Louwaars et al., 2009). The French and German Governments have issued legislation intended to prevent a patent on a gene or cell line contained in a plant variety from restricting the exercise of the breeder's exemption under PVP, which allows other breeders to use a PVP protected variety in further research without requiring permission from the holder of the PVP certificate (Louwaars, 2007). Globally, the trend in agricultural R&D has been characterized by an ebbing public sector and a rising private sector, aided and abetted by changes to IP. This implies that the costs of developing new plant varieties for many crop species are being internalized within the value chain, rather than being spread across all societal groups through general tax funding.

1.2 Objectives and research questions

The overarching question from an economic or policy perspective is how IP can best drive innovation as opposed to inhibiting or skewing its advance. IP policy is concerned with the configuration of both rights and responsibilities between farmers, seed companies, public research institutions and governments. In other words, what is both the form and scope of protection that countries should offer. The introduction of IP in the development of new plants allows a greater role to be played by the private sector and may present other options for public research institutions, such as concentrating on more basic research in plant science, or developing new plant innovations for crop species and market segments in which commercial incentives are lower.

The pertinent issue in this area relates to the patentability of technological tools (e.g. molecular breeding methods), genes and genetic constructs, and the living materials, such as plants, in which these are embodied. Initially introduced to address shortcomings in the applicability of utility patents to plant varieties, policy makers are considering changes to PVP that bring them closer to utility patents (Louwaars et al., 2009). At the same time, plant varieties in various jurisdictions are increasingly affected by patent protection over their components. This further shift towards patent or patent-like protection represents a broadening of scope of protection offered by IPRs in this sector and raises new questions about potential effects on the rate and direction of innovation. The prospect that patents in biotechnology could inhibit research through fragmented rights, increased transaction costs and greater uncertainty all to the detriment of innovation, has been captured by Heller and Eisenberg (1998) with their alarm call concerning the "tragedy of the anticommons".

[6] See, for example, Le Buanec (2005).

A related policy question is whether all countries should offer the same scope of protection. This question is one that is still very relevant for many emerging and developing countries (Correa, 2009). As illustrated above, the configuration of rights and responsibilities has evolved over time in the US and countries of the EU, as both technology and market circumstances have changed. Do developing and emerging countries have different interests, considering the characteristics of their agricultural systems in terms of degree of commercialisation and dependence of rural livelihoods on agricultural production and incomes?

Any informative perspective on the questions should recognise that there are different interests involved in considerations of IP policy. This can be seen in some of the earlier contributions in the economic literature, which emphasised differences between consumers and innovators interests (Arrow, 1959; Nordhaus, 1969a). As literature has developed, the configuration of interests analysed has become more complex, incorporating differences between innovators, possibly competing with each other and also different groups of consumers. Heterogeneity of interests and of effects is a recurrent theme in this thesis, in both theoretical and empirical analysis.

There is a relatively small body of literature devoted to exploring these questions, which is reviewed in chapter 2. This thesis aims to contribute further to this literature by attempting to inform three specific research questions, as discussed in the following sub-section.

1.2.1 Specific research questions addressed in this thesis

What are the tradeoffs involved in the scope or strength of intellectual property right (IPR) protection for an intermediate good, including seed? The traditional tradeoff in IP policy is between innovation and diffusion. Innovators earn monopoly rents for a fixed period of time in order to provide an incentive for upfront investment in research and development. The monopoly pricing entails a static inefficiency which temporarily reduces consumer surplus. IP policy can be interpreted as the extent or scope of monopoly conferred, for example in terms of the length of protection, the range of other products excluded, or the effectiveness of enforcement (O'Donoghue et al., 1998).

This tradeoff between interests has generally been analysed in the context of industries producing final consumer goods, with either product or process innovations. . In the case of plant breeding, these innovations in the form of new crop varieties are purchased as an input for farm production.[7] Farms sell their produce to food processors, wholesalers or directly for consumers. Thus, seeds are an intermediate good. Two issues may change the general or specific nature of tradeoffs involved in IP policy. One of these is the heterogeneity among farm enterprises, due to either different agro-ecological endowments, market factors or capabilities and behavior of their managers and staff. The second issue is the interdependence of farm enterprises that arises from the competition among them in the downstream market. This interacts with the first

[7] This analysis ignores the direct sale of seed to consumers for home gardens.

issue of heterogeneity in that one would expect that farms will not all profit equally from a new crop variety. Furthermore, the tradeoffs for one country might different from another, depending on the respective extent of innovative capacity as well as trading relations.

What are the effects of adopting IPRs, or increasing the scope of existing IPRs, on imports of agricultural seed and planting material? The theoretical analysis of the introduction IPRs indicates potentially different impacts depending on the nature and sector of the farm sector. In general though, it might be expected that the introduction of IPRs in countries should lead to an increase in the imports of protected products originating in other countries. Indeed, this is presumably why the TRIPS Agreement is so-named: IPRs are deemed to have a relationship with trade. In situations where a country is not importing any improved seeds, IPRs might stimulate the initiation of new import flows (what is referred to as expansion at the extensive margin in trade literature Helpman et al., 2008), regardless of whether the imported seed is already being produced without the innovators permission in the country concerned. In situtations where seed companies may already be exporting to a country, but forced to rely on other forms of protection, such as biological means (hybridization), they may be marketing only older or less valuable varieties due to the threat of reproduction by others. IPRs might then provide them an incentive to increase their exports, provided there is unmet demand, or to also export higher value varieties. Developing countries will expect some positive response in import flows, or possibly an increase in foreign direct investment, representing in either case an inflow of technology in exchange for offering exclusive rights to the production and marketing of agricultural seed.

What are the effects of adopting IPRs on investment and innovation in the plant breeding sector in developing and emerging economies? In addition to trade, the introduction of IPRs in developing countries is expected to stimulate innovation and investment in these countries, as proposed in the context of the TRIPS agreement. The simplest argument employed is that such countries lack strong innovative sectors, in part because of the absence of IPRs, meaning that innovators, including seed breeders, have little incentive to invest. IPRs are expected to promote the development of domestic innovative capacity and outputs, in the form of improved seed varieties. This process would include the emergence of domestic breeding companies, possibly evolving out of existing seed propagation and marketing organisations, which may have public sector origins. Foreign companies may also invest in breeding and seed production, either independently or as part of a joint venture with domestic partners. The extent to which this domestic sector emerges might depend, not only on the prospects for earning profits, but also on the relative importance of IPRs as an appropriability mechanism.

1.3 Scope and outline of the study

To address the questions above, this thesis brings together one comprehensive review and three separate research papers. The research papers consist of one theoretical analysis building on a stream of literature in industrial organization, and two distinct empirical analyses, one quantitative and the other qualitative. The three papers are not intended to constitute a systematic progression from theoretical development to its empirical verification. Rather they provide separate analyses that illuminate theoretical or empirical aspects of the general policy question concerning the scope of IPRs. The papers are united by their attention to international aspects of IPR policy, in particular the interests and experiences of emerging economies and developing countries.

The review (chapter 2) surveys the economic literature, and other closely-related literature, on the evolution of the IPRs in the agricultural plant breeding sector, concentrating on patents and PVP. It begins by reviewing trends in the use of these IPRs. This is followed by an assessment of research on the direct incentive effects and also the indirect effects on competition and downstream innovation. The chapter also addresses the state of knowledge concerning the effects on the interaction between public and private sector actors in this technological field, including some international aspects. This review does not devote much attention to what the broader economic literature has to say concerning these issues more generally, leaving this for the most part to the introductory sections of the various chapters that follow.

The first research paper (chapter 3) is an analysis of the tradeoffs involved in the extent of IP protection offered for an intermediate good. A theoretical model of a monopolist innovator supplying an intermediate good to heterogeneous producers is developed. Innovation is captured in a model of vertical product differentiation based on that of Mussa and Rosen (1978). The first paper thus extends that framework to a setting in which consumers with varying preferences are replaced by firms, in this case farm enterprises, that use the intermediate good to produce a homogeneous final good. This provides a relatively simple approach for assessing the effects changes in appropriability on the incentive to innovate. After examining the nature of tradeoffs in IPR policy - the scope of protection - in a single country case, the analysis is extended to a two country setting, in which an innovator is located in the North and serves not only the home market but also a second market of farms in the South. Two scenarios are considered: autarky and then the case where there is trade in the final product between North and South. This is intended to reflect the situation following the Uruguay Round and the entry into force of the TRIPS Agreement. Developing countries agreed to introduce IPR and in return expected improved access to markets in the North (particularly agricultural markets).

The second research paper (chapter 4) undertakes a regression analysis of the effects of PVP on the exports of seeds from the EU and the US to almost 80 countries, primarily developing countries. It thus attempts to assess how trade-related this type of IPRs actually is. A panel dataset is constructed of seed trade over the period 1989-2007. As two of the principal economies with capacity in plant breeding, the

EU and the US together account for at least three-quarters of global seed exports. A dynamic fixed effects quantile regression model, based on the general specification for the gravity model for international trade, is estimated to assess the effect of UPOV membership on seed imports.

The third research paper (chapter 5) assesses the experiences of five developing countries in implementing PVP. Also empirical in nature, this study uses qualitative methods to determine how different stakeholders in these countries are responding to this policy change. Responses were collected through a series of interviews primarily with private sector seed companies and public sector agricultural research organizations in China, Colombia, India, Kenya and Uganda. This provides insights into the use of PVP by these actors relative to other strategies for appropriating the innovation benefits embodied in new seeds. The study complements chapter 4 which concentrates on the effects of PVP on trade by examining the effects on investment, by both domestic and foreign actors. Given both the general lack of data on such investments (due in part to its strategic value and the secretive behaviour of actors) and the interaction with other forms of appropriability, a qualitative study provides insights into the range of factors motivating behaviour. This chapter also assesses the administrative requirements associated with the introduction of PVP.

The thesis is positioned between various streams of economic analysis on IPRs. On the one hand, it modestly extends the theoretical considerations on the scope of IPR that has been developed primarily within the sub-discipline of industrial organization. While much of the recent work in this area has concentrated on specific policy issues of interest to the ICT sector (e.g. copyright protection of software and other digital media; e.g. Choi et al., 2010), this thesis examines aspects of this overall question that are relevant to agriculture and plant breeding. In this regard, it complements recent work by Yerokhin and Moschini (2008) and also Burton et al. (2005). Secondly, the thesis contributes to the empirical body of knowledge on the effects of IPRs in stimulating innovation and its diffusion. In particular, the econometric analysis extends literature using cross-country data found in the specializations of international economics (Maskus and Penubarti, 1995; Smith, 2002) and agricultural economics (Srinivasan, 2004; Yang and Woo, 2006). The concluding chapter reflects on these contributions and some of the subsequent challenges for the research agenda.

Table 1.1: A comparison of IPR systems for plant varieties

	UPOV 1978 (Canada, various developing countries)	**UPOV 1991** (US, EU and member states[1])	**Plant patents** (available in US since 1930)	**Utility patents over plant varieties** (available in US since 1985)
Protected subject matter	Varieties of species listed by country	Varieties of all genera and species	Varieties of any asexually reproduced plants, except potatoes and edible tubers	Varieties of any sexually reproduced plant[3]
Duration of protection	Minimum 15-20 years (depending on crop)	Minimum 20-25 years (depending on crop)	20 years (from filing date)	20 years (from filing date)
Disclosure	Description of DUS variety otherwise through availability for breeding	Description of DUS variety otherwise through availability for breeding	Description and photographic drawing	Enabling or best mode disclosure plus deposit of novel material
Exclusive rights	Multiplication of variety for commercial purposes	Multiplication of variety for commercial purposes Use of harvested product for planting[2]	Reproduction or sale of patented plant	Multiplication of variety for commercial purposes Use of harvested product Any other commercially-related use (incl. breeding of new variety)

[1] In the US, PVP protection is only available for sexually-reproduced crop species.
[2] Under UPOV 1991 the farmers' privilege was removed although a member country is permitted to make exceptions. The US still allows a broad farmers' privilege, while the EU has restricted it considerably.
[3] In the US, as in the EU, and other countries complying with TRIPS Article 27(3)b, utility patents are also available for biotechnological inventions, including genetic transformation events and gene constructs, as well as for tools used in their creation, subject to the regular requirements for patentable subject matter.

2 The Dynamic IP system in plant breeding and biotechnology

2.1 Introduction

chapter 1 has introduced intellectual property rights (IPRs) in the agricultural plant breeding sector, including their historical development. The current chapter reviews literature on the recent increase in the importance of patent and plant variety protections and the dynamics of how this increase is playing out among various actors.[1] The discussion is organized according to the key issues that are of interest in understanding and refining the IP system. The first issue concerns a basic understanding of the trends in the use of the most important IPRs. The long-term increase in the use of IPRs leads in the third section to an examination of the fundamental incentive effect on innovation that IPRs are intended to provide, with a review of both theoretical considerations and empirical findings. A range of indirect, or secondary, effects of IP on the innovation system is then examined, including competition and market structure, the implications for sequential and downstream research, and also publically funded research actors, such as universities. Toward the end, some space is devoted to international aspects that have been examined. The final section offers a short assessment of overall trends in this field and gaps to be addressed.[2]

Aside from patents and PVPs, other instruments of IP protection are commonly used in this sector, including trademarks, geographical indications, and trade secrets. In some jurisdictions, geographical indications have also become available and relevant for the seed sector. Although their importance should not be denied, such forms of intellectual property protection are not addressed in this chapter, partly for reasons of space, but partly because they are arguably not as close to the core of the institutional dynamics being highlighted here. Another limitation is that the chapter concentrates entirely on the field of plant biotechnology, ignoring IPR issues of animal biotechnology, which are concentrated much more on tools and processes, as opposed to protection of final products.

[1] This chapter is adapted from Eaton and Graff (2013).

[2] To a large extent, this emerging area of research was summarized in the monograph edited by Santaniello et al. (2000), which included a number of papers presented at the second conference of the International Consortium on Agricultural Biotechnology Research (ICABR) in 1999.

2.2 Trends in the use of IP rights (IPRs)

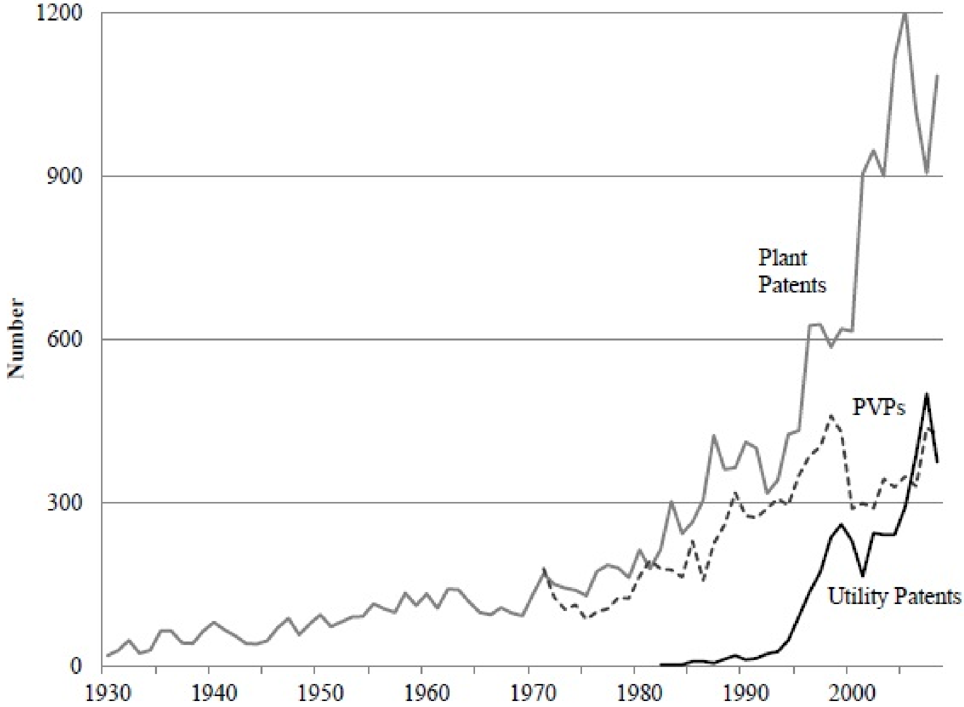
It is helpful to ground an understanding of how the IP system has evolved in some basic descriptive data on IP filings in the area of agricultural biotechnology and plant breeding. In most OECD countries, information on the application for and/or granting of formal IPRs, particularly PVP certificates, plant patents (where applicable), or utility patents, is generally available, and a number of researchers and investigators have systematically compiled databases that look specifically at developments in crop genetics and biotechnology. For PVP certificates and plant patents, each recorded application or granted title represents a relatively homogeneous data point corresponding to a newly developed crop variety. For utility patents, the situation is considerably more complex, as a wide variety of different types of technologies can be the subject of utility patents and existing systems of patent classification do not fully specify all of the possible technologies that may be utilized in plant breeding or biotechnology. This means that customized searches of classifications and even filtering on technical keywords is required to identify patents in these fields. Such compilations have been done most comprehensively in the US. In the early part of the 2000s, the Economic Research Services of the US Department of Agriculture (USDA-ERS) developed a database of US agricultural biotechnology patents (see Heisey, King and Day Rubenstein, 2005 and the USDA-ERS website). Graff, Rausser and Small (2003b) analysed US Patent and Trademark Office (USPTO) patent data on plant biotechnology patents and divided these into three key categories: patents on genetic transformation tools; patents on genes or genetic characteristics; and patents on elite plant germplasm or plant varieties. The most recent and most complete compilation of IPRs covering plant varieties in the US, including utility patents, PVPs, and plant patents, has been compiled by Pardey et al. (2012).

As indicated in Figure 2.1, applications for these three types of IPRs have grown significantly over time. In recent years, applications for plant patents and utility patents have continued to increase with some fluctuation and slowing in the growth of utility patents between 1999 and 2005. In contrast, applications for PVPs decreased considerably after the late 1990s and only recovered to similar levels by 2008. Pardey et al. (2012) offer possible explanations for these trends, including an increase in the mid-1990s in the average time needed for PVP applications to be processed. It is worth pointing out though, that despite some variability in the applications, the total titles in force for all three types of varietal rights in the US, has continued to grow.

Pardey et al. (2012) uncover more detailed trends as well. At the crop level, ornamental species account for over half of all varietal rights over the period 1930-2008 in the US, while cereals and oilseeds make up only 13% and 10% respectively. In general, ornamental species, most of which are asexually reproduced, are protected by plant patents, while the use of utility patents (possible only since 1985) have been dominated by corn and soybean.

In Europe, although neither plant patents nor utility patents are available for plant varieties, an analysis of the situation for PVP in Europe is complicated by the fact that protection was initially offered only at the national level. In 1996, a European

Figure 2.1: US IPRs over plant varieties, 1930-2008

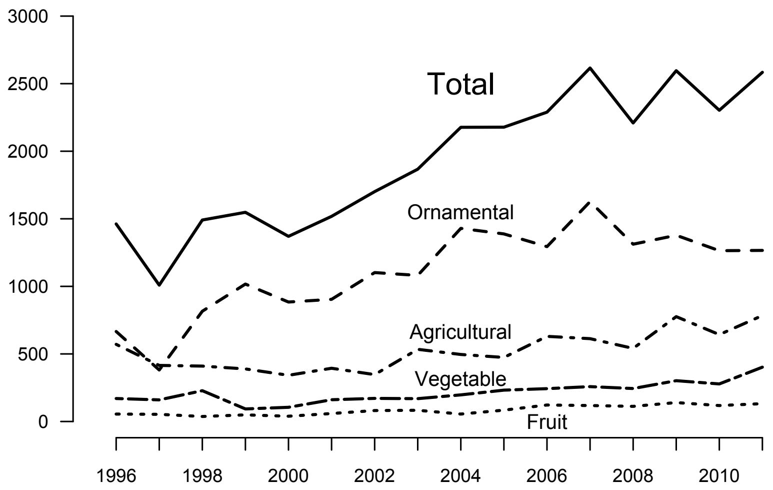


Source and Notes: Pardey et al. (2012), Figure 1, who note that "PVP indicates plant variety protection certificates. All data are reported by year of application. The PVP series represents the number of certificate applications, while the utility and plant patents are the number of granted patents taken here to represent patent applications."

Union PVP certificate became available with the establishment of the Community Plant Variety Office (CPVO), which now coexists with national level protection. A trend for plant breeders to opt for the broader, but more expensive, CVPO protection has resulted.

Although the UPOV Secretariat collates and publishes all PVP titles issued by all member countries, including the CPVO, there is not an available database that easily identifies specific varieties with protection at both the national and European levels, or at the national level but in multiple member countries. Figure 2.2 shows trends in PVP titles granted by the CPVO from 1996-2011 by crop group. The total number of titles granted displays an upwards trend. This may be even stronger given that holders of existing national-level rights were initially offered a grace period to register these with the CPVO after introduction of the EU PVP. For most crop groups with the exception of ornamentals, the number of PVPs granted has fluctuated somewhat

Figure 2.2: Trends in PVP titles granted annually by CPVO by crop group, 1996-2011



Source: Community Plant Variety Office (www.cpvo.europa.eu)

over the first 10 years, before starting an upward trend during the last 5-6 years. For ornamental crops, which account for more than one-half of the titles granted (similar to proportions observed in the US), the pattern is reversed with strong growth until 2007 and a stable pattern since then.

The recent trend of increasing numbers of PVP titles at the EU level probably continues an earlier trend in individual member countries. Although a comprehensive assessment is lacking, Louwaars et al. (2009) document a long-term increase in the number of PVP titles granted in the Netherlands (though with data only going back to 1964, not 1941 when PVP was first made available), which currently accounts for one-third of all CPVO applications. They also show how the number of PVPs granted in the country declined considerably in the mid-1990s, coinciding with the introduction of the CPVO right. Total PVPs granted for ornamental crops continued to decline after 1996 while those granted by the CPVO continued to grow. In contrast, the number of PVPs granted in the Netherlands for non-ornamental crops fluctuated at about 100 grants per year over the period 1999-2005, while total CPVO grants for such crops fluctuated between 500 and 800 per year with no clear trend. Further data collection and analysis is therefore required to assess the trends in Europe over the past 15-20 years.

Describing the basic trends in the use of utility patents for protection of genetic transformation tools and genetic characteristics is more complicated. Graff et al. (2003a) detailed trends in plant biotechnology patents for the USPTO, the EPO and the Japanese Patent Office (JPO) and those registered under the Patent Cooperation Treaty (PCT) from 1980 to 2000. Those results demonstrated an exponentially increasing number of patents issued in the US through 2000, with more moderate numbers and rates of growth of patents granted by the EPO and JPO. They also demonstrated how the public sector was relatively active in patenting in the field of plant biotechnology, compared to other fields of technology.

Buccola and Xia (2004) examined a relatively small subset of USPTO patents issued from 1985 to 2000, restricted to those patents concerning cellular or molecular level technologies, representing key tools of biotechnology, with the set totaling 691 patents. The data exhibits a marked increase in the number of patents granted from the late 1980s through the mid-1990s. They also attempted to proxy for the quality, or value, using a count of "forward" citations, the number of subsequent patents that cite the subject patent, finding that mean citations per patent declined substantially by the late 1990s (even after attempting to account for truncation bias).

The analyses by Graff et al. (2003b,a); Buccola and Xia (2004) provide important insights about basic trends in biotechnology innovation based on the use of the patent system. Given the long-term nature of the R&D process, it should be considered a priority to carry these analyses forward with updating of data from the first decade of the 21st century. (An interesting recent analysis by Agrawala et al., 2012 examines patenting data from 1990-2006 for trends in innovations in crop biotechnology for evidence of R&D to address climate change adaptation challenges in agriculture.) In particular, more effort could be devoted to linking and matching the use of different IPRs in combination or in different jurisdictions. The identification and classification of IPR applicants and their geographic location is also important information for studying trends in which types of organizations (or individuals) apply for patents. This is becoming more relevant, while at the same time more difficult, as patent applications in plant biotechnology are increasingly coming from emerging economy countries, such as China and India. In addition, there have been only a few studies based on input from breeders and plant scientists (e.g. Graff, Zilberman and Bennett, 2009; Lei, Juneja and Wright, 2009; Tripp, Louwaars and Eaton, 2007), an approach that provides valuable insights; greater collection and use of such data would be useful in understanding the trends, as well as driving forces, in the use of IPRs.

The growing use of the IPRs poses the fundamental question as to whether the apparent increase in innovative activity is stimulated in part by the availability of these forms of protection. In addition, questions arise about ownership structure and implications for market power, with possible effects on the rate or direction of innovation in the breeding sector (Graff et al., 2003b,a, 2009; Goeschl and Swanson, 2003). In general, it is difficult to distinguish between evolution in the innovation process that might be exogenous from the influence of the IP system and the extent to which changes in the IP system itself are driving shifts in the innovation process. The remaining sections of this chapter make an effort to consider such questions and review contributions that have been made toward answering them. The final section will reflect, however, on how little is still known about the dynamic IP system.

2.3 Direct incentive effects

The fundamental question of whether patents and other IPRs enhance the incentive to innovate has not received much systematic attention from researchers, which may seem surprising given how central this presumed effect is to the rationale for an IP system. It is often just taken as common sense that IP protection and the assumed facility to earn an economic return is required for innovators to invest. Still, this view has throughout history been contested in debates concerning national patent systems in particular; for a historical review, see Lerner (2002). There is scant empirical work, even for other technology classes, with the study by Cohen, Nelson and Walsh (2000) standing out. As an update of a much-cited paper by some of the same authors (Levin et al., 1987) they conducted a survey of US industry and found that patents were not viewed as being among the most important strategies for earning profits from innovations. More recently, Boldrin and Levine (2008a, 2009) offer a similar, though more contested, analysis of this issue. These critical perspectives emphasize that innovators have a range of means to protect access to their innovations and thus to generate profits (or capture rents). Some commentators have noted that increasing inefficiencies in the operation of the patent or copyright systems may partly undermine the effectiveness of IPRs as a means of stimulating innovation or its diffusion (Jaffe and Lerner, 2004). A recent analysis commissioned by the European Patent Office (2007) indicates that authorities administering the patent system do take such concerns seriously.

An important finding by Levin et al. (1987) was that patent protection was more important for industries, such as pharmaceuticals, with a product that was relatively easy to copy and for which only a limited amount of secrecy is possible (in the case of pharmaceuticals, given the testing and disclosure requirements of health and safety regulations, most the information required to replicate the invention is revealed). This is very much the situation in plant breeding, given the self-reproducing nature of agricultural crops, a fact that was recognized in debates in the 1920s in the US leading to the development of the Plant Patent Act (1930).

2.3.1 Theoretical analyses of the direct incentive effects of IPRs

The basic starting point for theoretical models is the non-excludable characteristic of the final product of crop breeding or biotechnology, since new crop varieties are to various extents self-replicating technologies. A basic assumption is that the innovator, the breeder, has no technical means of completely excluding others–whether they are farmers or competitors–from obtaining samples of seed and reproducing it, either for own use (by replanting of seeds), or for sale on the secondary market. The resulting non-appropriability of returns means that incentives to invest in R&D are generally insufficient relative to social needs. Hence legal means in the form of IPRs are required, or other solutions, such as public subsidies or provision of breeding and seeds for farmers.(other solutions to this problem used both in agriculture and other industries include public subsidy for research, explicit market monopoly [above and beyond that offered by IPRs] and direct public provision of research)

Still, there are various strategies and technological means by which the developers of new plant varieties can and do enhance their appropriability. Hybridization is probably the most important of these, partly because it is a purely biological mechanism. Griliches (1957, 1958) did the classic study of the nature of this form of excludability within the process of technological change in the case of corn in the US market in the first half of the 20th century. It is worth noting, however, that the extent of appropriability that can be achieved using hybridization varies considerably depending on the biological characteristics of specific crop species, with general distinctions being drawn between cross-fertilizing (most amenable to hybridization), self-fertilizing, and vegetatively-propagated species (in descending order of the ease with which the crops can be protected by biological means).

Moschini and Lapan (1997) introduced a framework to investigate the distribution of benefits from new agricultural biotechnological innovations, in particular the extent to which the innovators of GM crops are appropriating returns on their investment. Note that this framework can be applied to any kind of agricultural innovation that is purchased by a farmer to enhance productivity. There is nothing about it that is inherently concerning GM crop varieties, but as these were delivered with greater restrictions due to IPRs, it became relevant to examine the resulting impacts in terms of efficiency and equity. Moschine and Lapan adjusted existing analyses of the welfare benefits from agricultural innovations (e.g. Alston, Norton and Pardey, 1998) to explicitly account for the monopoly power arising from IPRs, in particular from patents over GM varieties, and thus allowing for the generation of monopoly rents. Their theoretical model once calibrated allows estimates of the distribution of net benefits arising from GM varieties among the innovating seed company, farmers, and consumers. This framework was applied subsequently in numerous studies to show varying shares of benefits accruing to different actors (Sobolevsky, Moschini and Lapan, 2005 for herbicide tolerant soybeans; Falck Zepeda, Traxler and Nelson, 2000 for Bt cotton; Pray et al., 2001 for Bt cotton in China). This line of research thus allows a rough estimation of the benefits appropriated by the innovator.

One question is whether some of the net benefits measured using the Moschini and Lapan (1997) framework are due to the earlier evolution of the IP system, especially the protection for GM constructs and varieties. But in most such analyses, no effort is made to disentangle the influence of other factors on the strength of incentives to innovate, such as other appropriation strategies. Such an interpretation would have to recognize that, even in static terms, certain other social costs have not been included in the calculation of net social welfare, in particular the transaction and administration costs of granting and enforcing IPRs, as well as costs arising from regulatory requirements concerning GM crops, which are often covered by innovators using rents appropriated under the IP regime (see Phillips, 2003). In any case, a static welfare analysis does not link the monopoly profits to the incentive to invest in R&D, nor does it examine variations in the extent of appropriability as related to IPRs.

In plant breeding, the potential to earn profits is closely tied to the possibilities for discouraging or restricting farmers from saving seed. This practice, also referred to as planting progeny seed, is still very prevalent in less formal or less commercial seed systems (see Tripp et al., 2006, for a discussion), although it is limited to self-fertilizing and vegetatively-propagated crop species due to the manner of biological reproduction. The development of hybridization for certain species starting in the 1920s and 1930s provided a technological means to encourage farmers to purchase new seed for each cropping season, since progeny seed saved from such varieties performs relatively poorly and inconsistently. In developing countries, farmers have saved progeny seed from purchased hybrids to cross these with local varieties which has provided a channel of technology diffusion (Tripp and Pal, 2001). Using legal means, patent protection also excludes this practice, as do most countries' PVP systems, with the UPOV 1991 Act establishing the most common and the strongest standards for national PVP laws while allowing a member country to make exceptions in its legislation. Enforcement of IPRs to exclude farmers from saving seed is neither perfect nor costless, and the innovator is generally required to expend resources to identify and pursue legal action against potential infringers. Alternative systems have been established in some European countries under which farmers associations agree to an additional royalty payment to acquire permission to replant (Gray, 2012). For GM crop varieties, seed companies have typically sold seed to their client farmers only under contracts in which they agree not to save seed, and there have been cases of alleged breach of contract and patent infringement brought before the courts in both the US and Canada concerning GM varieties. In some Latin American countries including Brazil, Monsanto has developed arrangements to collect seed royalties from farmers at the point of sale of the harvested crop, in the case of herbicide-tolerant soybeans (Traxler, 2006).

Though relevant only for non-hybridized crops, this issue has been politically controversial since it entails a shift in legal rights, and is similar in some respects to changes introduced by copyright protection for software and digitalized entertainment media where encryption, "click-through" user agreements, and other forms of technically or contractually-based copy protection have become important appropriation mechanisms. In the case of crop seed, biotechnology has opened a possibility comparable to software encryption by engineered seed sterility. Such engineered control over seed viability has been referred to as genetic use restriction technologies (GURTS) technology protection systems (TPS), and more figuratively by some civil society organizations opposed to the technology as "terminator technology". Planting of progeny seed could be restricte by varietal GURTS, which are distinct from trait-specific GURTS. The latter may be designed to convey agronomic benefits (see Visser et al., 2001). In any case, GURTS have not been commercialized and seed companies have publically announced that they do not intend to develop and commercialize such technologies.

It is important to note, however, that GURTS could serve a separate purpose: to reduce the possibility of unauthorized spread of genetically modified organisms beyond the fields in which they have been intended for planting. This would provide a mechanism to support biosafety regulations and to reduce potential liability for the seed company (Smyth and Phillips, 2002). At an international level, the controversy around GURTS reflects concerns of the potential implications in developing countries, where it can be much more difficult to establish and enforce fully-informed contracts with farmers. Furthermore, the practice of saving seed is much more prevalent and economically important in developing countries, where there has long been a flow of seeds between formal and informal (or less formal) seed systems.

There are few formal analyses of the various incentives and tradeoffs that the evolution of the IP system has meant in terms of reducing farmer's rights to save and reuse seed in exchange for the prospect of being able to purchase and use improved seed varieties. An early paper by Heisey and Brennan (1991), predating the commercialization of modern biotechnology, developed an analytical model of demand by farmers for replacement seed. The context for their model was one of developing country wheat production and efforts by international agricultural research centers (IARCs) such as CIMMYT and national partners to encourage more frequent seed purchasing – effectively a formalization of the seed supply system but still largely involving public sector actors – in order to boost agricultural sector productivity and food security. The core of their work is the tradeoff farmers face between the higher cost of more frequently purchased seed and the deteriorating performance of progeny seed; this tradeoff is arguably sharper for farmers in many developing countries due to greater difficulties in accessing credit.

This tradeoff suggests the application of models for durable consumer goods. Burton et al. (2005) look systematically at alternatives for the innovator to increase its share of profits by enforcing the restrictions on reusing seed in a two-period model. Their model incorporates the basic vertical product differentiation setup with farmers differing according to how much profit they can generate with the seed. They analyze three alternative options for the monopolist innovator, including two types of contracts and a GURT. This analysis incorporates a probabilistic success of enforcement of contracts by the monopolist and the associated monitoring and transaction costs. Their theoretical results suggest that GURTS would enhance profits for innovators, while farmers (as a whole) would benefit more from contracting. This paper is among the first in the agricultural biotechnology field to incorporate elements from the more extensive literature on piracy and copyright protection (e.g. Shy and Thisse, 1999). Burton et al. (2005) do not incorporate the effects of the differing degrees of appropriability on the incentive by the monopolist to invest.

Alston and Venner (2002) develop a model to examine the incentive that the degree of appropriability accruing to a monopolist, as represented by the royalty rate, has on the incentive to innovate. Less than complete appropriability of returns could be optimal, even for the monopolist, if it generates greater demand. This model is extended by van Tongeren and Eaton (2004) to a two-country setting to assess social welfare effects. Extending this analysis to two countries exploits the potential for price discrimination, which also yields efficiency benefits. The analysis in chapter 3 of this thesis aims to contribute to this general literature by combining variable degrees of appropriability with heterogeneity of farms as purchasers of seed and producers of a final consumption good. In addition, an extension to a two countries is also analysed.

The degree of appropriability can also be interpreted in terms of the potential for infringement and enforcement. Giannakas (2002) develops a theoretical model that assesses the welfare benefits of adoption by farmers of an IP-protected variety in a developing country. The analysis illustrates the idea that permitting a certain amount of infringement on the IPR can have benefits in terms of greater diffusion. This arises ,naturally in a vertical product differentiation framework with incomplete adoption of a product or innovation. This is a common theme in the economics literature on IP; although monopolist profits may be maximized with very strong IPRs, and innovation may also be faster, social benefits may be greater with less than maximum possible scope or less than perfect enforcement of IPRs. Such a tradeoff is similar to the more traditional case of balancing static and dynamic benefits in the length of patent protection (Nordhaus, 1969b,a; Scotchmer, 2004).

2.3.2 Empirical analyses of the direct incentive effects of IPRs

The incentive effects of IPRs can be looked at in terms of a number of measures, which in general can be divided into two groups, R&D inputs and R&D outputs. In principle these can be described in terms of quantity and quality, but in practice the former receives the most attention due to relative ease of measurement. R&D inputs are typically assessed in terms of financial investments or the allocation of human R&D resources. R&D outputs are measured in terms of new innovations registered for protection with IP authorities, in particular the granting of patents or plant variety protection registrations. Measures of the quality of R&D outputs would incorporate productivity improvements in downstream production processes, but this possibility has been exploited in only a few studies. Estimates of these benefits have though been addressed in studies of returns to R&D in crop breeding and improvement, some of which are mentioned above, where the specific role of IPRs in stimulating the R&D was not the research focus.

Prior to the introduction of modern biotechnology into the plant breeding sector, attention in terms of IPRs focused on the effect of the introduction of PVP, on both inputs and outputs of R&D. PVP offers a discrete event, and historical trends can be examined using statistical and econometric methods to ascertain shifts in innovation that may be attributable to the change in the IP system. Most studies of the effects of PVP introduction have been undertaken in the US but a few have looked internationally.

A recent historical review of the effects of the US Plant Patent Act of 1930 has been undertaken by Moser and Rhode (2011). They concentrate on rose breeding, which accounts for more than half of the plant patents issued in the US between 1930 and 1970, when the Plant Variety Protection Act was enacted (though this did not replace the Plant Patent Act, as explained above). Moser and Rhode demonstrate how the number of rose varieties patented has accounted for only 16% of total rose varieties registered during this period, with the proportion actually declining from about 1950 onwards. They conclude on the basis of this and other circumstantial evidence that the availability of plant patents has had at best a “secondary effect” on the development of the US rose breeding sector.

Butler and Marion (1985) used data on certificates and a survey of breeders to examine changes in breeders’ behavior as a result of the US Plant Variety Protection Act (PVPA) enacted in 1970. The study estimated R&D investments and found a rapid increase in the period leading up to the Act, possibly in anticipation of its passage. The study found evidence of increased investment in a few specific crops, which was also concluded in a follow up study by Butler (1996), showing an increase in the number of soybean and wheat crop varieties released in the 1970s . These studies are generally perceived as indicating (though not confirming) that the PVPA had a positive effect on R&D incentives for a limited number of crops.

Perrin, Hunnings and Ihnen (1983) surveyed seed companies for data on research expenditures in light of PVP introduction. They also found evidence of a significant increase in research expenditures for a number of crops, including not only hybrid crops. This study also looked at investments as a percentage of seed sales and in terms of dollars of research per dollar of crop value. The general conclusion was that PVP stimulated a marked increase in these investments.

Using econometric techniques, Perrin et al. (1983) also found evidence of a weakly-improving trend in soybean yields in test plots after the introduction of PVP in 1970, an early study assessing the potential effects of PVP on agricultural productivity. On the other hand, Alston and Venner (2002) found no statistically significant evidence that PVP had stimulated improvements in commercial or experimental wheat yields and Venner (1997) found no evidence for increased private sector investments in this crop (other studies are documented by Lesser, 1997). Similarly, Carew and Devadoss (2003) regressed canola yields, for 1995-2001 for 12 growing areas in Manitoba, on a range of variables including the proportion of land planted to varieties protected by PVP, as well as to varieties genetically modified for herbicide tolerance and to hybrid varieties in general. Whereas those varieties protected by PVP tended to be open-pollinated, the genetically modified varieties were protected mostly by technology use agreements. Carew and Devadoss controlled for other factors, including fertilizer use as well as spatial and temporal diversity of varieties planted in each growing area, but found only weak evidence of an effect of PVP on canola yields. Naseem, Oehmke and Schimmelpfennig (2005) conducted a similar study on cotton yields for 10 US states over the period 1950-1996. With a longer set of panel data, they were able to also include a trend shift variable for when PVP is expected to start influencing farmers’ yields (including a delay for the long-term nature of breeding), and interacted that the proportion of area planted to protected varieties. The results suggest that the combined effect of PVP was to increase yields by about 8-10%. Further work of this sort would help to clarify the seemingly mixed effects of PVP on breeding and productivity. As yield is only one measure of productivity, and not necessarily the most important one to farmers, continued work in this area should incorporate other productivity measures and preferably indicators of economic performance, which account also for the costs of inputs, including seeds. This would allow a more thorough economic assessment.

Taking an international perspective, Diez (2002) assessed the trends in the number of varieties registered in Spain over the period 1974-1991, covering the period in which PVP was introduced in the country, first for wheat, barley, rice, potatoes and oats in 1975, with protection extended later to sunflower, alfalfa and maize. Following PVP, the number of varieties registered and protected by private breeders increased, as did the registration of varieties by foreign breeding companies. However, the analysis does not control for other market-related factors such as overall trends in Spanish economic policy which may have played a role.

Jaffe and van Wijk (1995) examined the impact of PVP on R&D in Argentina using a survey of plant breeding firms. While this study found that investments had increased between 1986 and 1992, survey answers indicated that changing economic policies and market liberalization had provided more of an incentive than the introduction of PVP. Leger (2005) undertook an interview-based survey of effectively all companies and public sector organizations involved in maize breeding in Mexico where PVP was introduced in 1997. There appeared to be little increase in breeding programs that could be attributed to the introduction of PVP, which was primarily being used by public breeding organizations. These results may largely reflect the fact that maize varieties can be protected reasonably well from reproduction through hybridization.

In the case of patents for agricultural biotechnology, it is fairly clear that the landmark cases in the US represent the key change in IP policy of relevance that caused patenting applications and grants to subsequently increase. There were similar changes in the interpretation of Canadian patent law which allowed the patenting of genes (described in Galushko et al., 2010), followed by similar possibilities in European countries. This effectively extended the scope of patents to protect uses of the plants and even plant varieties in which such genes had been inserted, as illustrated by the decision in the Monsanto vs. Schmeiser case mentioned above. The sharp rise in the number of patents granted and GM crop varieties subsequently developed and marketed—particularly by the private sector—is generally interpreted as evidence that the changes to the allowable subject matter for patents and associated claims induced such investments. Although this has not yet been analyzed systematically, some anecdotal evidence suggests that additional factors also play a role. In particular, the dominant innovation pathway of genetic transformation of crops has been confined largely to crops and varieties for animal feed and industrial purposes. There has been much lower R&D output in crops destined for direct human consumption as food, at least partly due to the social controversy and the cost of compliance with the attendant regulatory frameworks that have been put in place. The latter include costs of complying with requirements for segregation and traceability, which may well have also influenced the directions taken by research and innovation.

2.4 Competition and market structure

The standard economic model views patent protection as a temporary monopoly right given in exchange for the investment of resources in R&D and the disclosure of the resulting invention.[3] What is often overlooked, however, is that monopoly power is limited by the extent to which there are competing products or processes. The economic literature differentiates between drastic and non-drastic (or radical and incremental) innovations as a means to distinguish between those innovations for which few substitutes are available and those innovations whose improvements confer only a relative, as opposed to absolute, advantage for the innovator.

Duopoly models are often employed to examine the effects of changes in IP policy and regime on the incentives facing competing innovators, as well as the likely outcomes in terms of rates of innovation, pricing strategies or market share. In the area of plant breeding, one attempt to look at specific questions of this nature is Eaton and van Tongeren (2006), which proposes a simple static model of vertical product differentiation with interdependence in research costs between two firms. The extent to which the breeders' exemption is limited by patent policy (or a further refinement of PVP policy) affects the extent to which each firm benefits from spillovers from the other's research.

Moschini and Yerokhin (2008) provide a more complete theoretical analysis of the breeders' exemption in a dynamic model employing stochastic game theory, which has become a standard workhorse in the industrial organization literature (Doraszelski and Pakes, 2007). Their model illustrates the intuitive idea of how a research exemption in patent policy, and its parallel, the breeders' exemption in PVP, may reduce the incentive to invest in large, costly breakthrough inventions, since competitors will follow on with smaller improvements that take market share away from the initial inventor. This is the rationale behind the proposition that genetically modified crops would not have provided an interesting enough opportunity for private companies without the more exclusive protection offered by patents. Some actors in the seed sector have indeed argued that the decreasing gains to traditional breeding strategies justify this increase in scope of IP protection, especially when viewed in light of how genetic sequencing has reduced the cost of decoding the makeup of rival crop varieties and thereby the cost of imitating them (Janis and Smith, 2006). As Moschini and Yerokhin (2008) point out, their findings can also be interpreted as an argument for the provision of fundamental, upstream research through public funding (see Malla and Gray, 2003). An additional point to make about this analysis is that it ignores

[3]The latter purpose of the patent system, encouraging disclosure of innovations, is often forgotten or ignored in economic analyses of agricultural biotechnology. A more active literature among legal scholars has given this social benefit more attention. Landes and Posner (2003), for example, suggest that the benefits from disclosure and its resulting spillovers are greater than the direct incentive effects. It seems plausible that the relative importance of the disclosure function of the patent system, in comparison to the direct incentive effects, is likely to be greater in technological fields where the threat of imitation is not as great. This may be the case with process innovations in agricultural biotechnology, such as the tools of genetic sequencing and engineering, but less so with the product innovations, particularly new crop varieties, due to their self-reproducing nature.

possible differences in the innovation pathway pursued, an area that remains relatively unexplored in the theoretical analysis and which could lead to a qualification of results on the research exemption.

It is worthwhile to pause to consider the value of these models, as it is often not well understood that this area of theoretical work is still young and very much piecemeal. Each specific contribution builds upon the overall body of knowledge and thus is best interpreted in that context. Stylized models necessarily ignore numerous aspects of a question and the results are thus often predicated on assumptions that could usually not be defended in real-world situations. The body of theory emerges as attempts are made to capture different salient aspects into formalized and generalized models. The models developed and described above are inspired by the sector of plant breeding and agricultural biotechnology, but their stylized nature means that they are not necessarily specific to the sector. They build on a much broader body of literature which is not reviewed here.

2.4.1 Empirical analysis of the influence of IPRs on competition and market structure

The availability of patent protection for genetic constructs, the tools for creating contructs as well as complementary products such as herbicides (glyphosate), has stimulated increased concentration in the seed and agrochemical sector. Hayenga (1998) documented the trends in the US at the end of the 1990s which involved a large round of mergers and acquisitions in the sector and precipitated antitrust cases by the US Department of Justice. The late 1990s also heralded a wave of considerable litigation amongst agricultural biotechnology companies, centred on patent infringement, including interpretation of the terms of licensing contracts. The engagement of the Department of Justice indicates that the potential for this technological and IPR-driven process of vertical and horizontal integration to reduce competition in the seed and agrochemical sector was being taken seriously. International trends in the concentration of PVP rights were analysed by Srinivasan (2003a), providing additional, indirect evidence of these trends.

There have been very few studies that have examined the specific reasons for the restructuring and increased concentration in of the US plant breeding and seed industry in the 1990s. Graff et al. (2003b) propose that the restructuring was at least in part due to the potential profits from exploiting complementary intellectual assets, including tools of genetic transformation, genetic constructs, and elite germplasm, which were generally assets belonging to different actors holding IP protection. This explanation is based on the reduction in transaction costs and uncertainty in coordinating asset complementarities that acquisition allows (Teece, 1986; Milgrom and Roberts, 1990). Their econometric model is based on the patent production function pioneered by Grilliches (1979) and Hausman, Hall and Griliches (1984) in which the number of patents per company is a function of its R&D spending as well as other characteristics. Using the dataset of US patents mentioned above, Graff et al. measure complementarities between different types of patents as the positive covariance in the unexplained variation in patent counts, and found that this had increased under the concentrated industry structure observed in 1999 as compared to the less concentrated structure of 1994 before the wave of mergers and acquisitions. The results provide support for the asset-complementarities explanation of industry trends, relative to other proposed explanations that emphasize strategic motivations to erect barriers to entry or engage in strategic patenting (i.e. accumulating patents as bargaining chips). To date, an update of this study has not been published, nor has a similar exercise been undertaken using EPO data, both of which would be worthwhile at least to inform understanding of evolving trends in the industry and the role of IP.

Marco and Rausser (2008) likewise looked at mergers and acquisitions activity in plant biotechnology the 1980s and 1990s. They develop an econometric model to explain consolidation in the sector with US patents being held by firms as one of the explanatory variables. They also included a measure of the enforceability of patents based on the predicted probability that a court would rule a patent valid and infringed. The average enforceability of a firm's patent portfolio was found to be positively correlated with the probability that the firm would be involved in consolidation.

Using tools of industrial organization, a few papers have assessed whether recent trends towards restructuring have led to increased prices for seed. Shi, Chavas and Stiegert (2010) estimated a mark-up price equation for corn seed in the US market for the years 2000-2007 and found evidence that trait bundling was characterised by sub-additive pricing of seed, reflecting either economies of scope in bundling of GM traits or complementarity in demand for those traits. Shi, Stiegert and Chavas (2011) found similar results for the US cottonseed market with data from 2002 to 2007. Importantly, while they also found evidence of increased seed prices, as theory would predict, they suggested that this is not excessively inhibiting diffusion. Reflecting on this and other evidence, Stiegert, Shi and Chavas (2010) point out that whether the evolving market structure, with increasing concentration and vertical integration, will maintain sufficient competitive pressure in the sector remains a relevant topic for research and policy attention.

2.5 Public research, technology transfer, and freedom to operate

Considerable attention has focused on the effect of IP protection on the reconfiguration of roles between public and private sector actors in agricultural research. One concern is that the increased possibilities for seeking IP protection will alter incentives and shift the relative focus of public research institutions, diverting publicly funded research activities towards more applied topics with greater commercial—although not necessarily social—benefits. In the US, researchers have attempted to assess the impact of the Bayh-Dole Act of 1980 which harmonized IP rules under the different US federal agencies that fund research and encouraged the institutions that receive federal research funds to apply for patent protection. One clearly stated purpose of this legislation is to stimulate the uptake and commercialization of such publicly-funded research.

For the US, Barham, Foltz and Kim (2002) studied trends in patenting by universities over the 1975-2000 period and noted starting in 1995 a marked increase both in the number of patents and their citation rates, suggesting increased quality or value of innovations. There is also evidence of path dependence and increased concentration of innovation among fewer universities, although this is mitigated somewhat once the value of patents, in terms of citations, is taken into account.

A wider view of patenting trends was examined by Graff, Cullen, Bradford, Zilberman and Bennett (2003a), using patent data for technologies relevant to the agricultural biotechnology and plant breeding sector from the US, Europe, Japan, and WIPO. This analysis found that public sector research institutions accounted for 25% of the total stock of patents in the agricultural biotechnology field , while the private sector accounted for the remaining 75%. The study also showed that while a handful of major companies enjoyed relatively consolidated patent portfolios, patent holdings in the public sector were, as would be expected, highly fragmented across separate institutions. Under the situation indicated in Graff, Rausser and Small (2003b), in which a diversified portfolio of different complementary IP appeared to be advantageous or even necessary for access to market, it appeared that any technologies generated by public sector researchers might be dependent upon technologies tied up in the major companies' IP portfolios, making it potentially difficult for public sector institutions to serve the crop genetic needs of their traditional stakeholders using GM technology.

Relatively little attention has been given to the role that IP plays in shifting the research priorities of public sector plant biotechnology researchers and plant breeders. At issue is whether public sector researchers would concentrate more efforts on innovation pathways that are more likely to deliver higher revenue generation opportunities, in effect directly catering to or even competing with the private sector. For example, in an interview survey of the effects of both PVP and patent protection in five developing countries by (Tripp et al., 2007; see chapter 5), public agricultural research organizations in both Kenya and India reported that PVP protection implied an expectation for these organizations to earn revenues. In their review of the GM canola sector in Canada, Galushko, Gray and Smyth (2010) report findings from a survey of breeders that reveals a lack of strategic coordination of the relative roles of the public and private sectors. In theory, and as argued by Tripp et al. (2007), the development of IP protection possibilities, as part of a larger process of increased commercialization of R&D in the breeding sector, should allow the public sector to relinquish those traditional research pathways that have commercial potential, leaving those efforts to the private sector. The public sector could then concentrate on market and crop segments of less interest to the private sector. In particular, this could include "orphaned" crops of importance to the low income smallholder farmers, which is particularly relevant from an international perspective. An alternative role for public sector research is to concentrate on more basic, upstream research with broader potential to generate economic spillovers and stimulate downstream innovation pathways. Or the public sector could simply reduce its agricultural research efforts freeing up resources to devote to other more pressing public priorities (Malla and Gray, 2003).

A second concern affecting public research organizations is the potential for increased use of IP protection to restrict or shape the research plans of plant scientists and breeders. Lei, Juneja and Wright (2009) surveyed scientists at several US universities regarding what effects the patenting of research tools in the field of plant biology may be having over their research programs. The scientists surveyed reported that IP protection of research tools does have a negative influence on their research. The precise mechanism is, however, typically indirect. Administrators, who perceive potential for revenue from patented research tools, tend to require the use material transfer agreements (MTAs), a type of inter-institutional contract that stipulates the legal terms under which a proprietary tool can be used in research by the recipient. The negotiation and execution of MTAs impose costly delays on the exchange of research tools, with fully 42% of respondents reporting delays of research projects due to delays in obtaining a requested research tool and 27% reported that they ended up using alternative, sometimes less effective, tools than the one the one they had preferred. Still, most scientists disregard patents altogether, with 91% of scientists reporting that they had never checked whether a research tool is patented.

Galushko et al. (2010) examine the case of GM canola in Canada. Using a survey of breeders in both the public and private sectors, the study seeks to assess the impacts of increased use of IP protection on innovation investments and also the sharing of information, research tools and germplasm among breeders. Interestingly, the most common reason cited for increased protection of research tools and germplasm was as a response to increased patenting by others and thus the desire to ensure freedom to operate. Such a result is not that surprising given the large share of the sample accounted for by public sector breeders, who are likely to have less motivation to seek IP protection for revenue generation purposes. They conclude that ensuring freedom to operate in the canola sector is becoming costly and time-consuming and suggest that the effect of this on the rate of innovation deserves further attention.

The role of the public and private sectors, and the freedom of the former to operate, has additional implications for international agricultural research intended to contribute to agricultural growth in developing countries. Binenbaum et al. (2003) undertook a review for staple crops and concluded that there were few restrictions on developing country researchers in place at that time. Protection in developing country jurisdictions had been applied for on only a very limited basis. Furthermore, only a small proportion of developing country agricultural production is exported to developed country markets where there is greater potential for infringement to incite enforcement and litigation measures. This situation may have changed in the interim as many developing countries have subsequently agreed to IPR provisions in free trade agreements negotiated with either the US or the EU; however, actual patent filing trends may take time to respond to such changes. Regardless, despite such findings, the potential uncertainty regarding freedom to operate may cause reluctance among national agricultural research systems or international agricultural research centers (IARCs) to invest scarce resources in lines of research that could be impacted.

2.6 International transfer

Another premise for the strengthening of IPRs internationally is its potential for stimulating trade in final goods as well as foreign direct investment to transfer higher technologies for economic production. While there are a number of studies that look for correlations between a country's strengthening of IPRs and flows of trade or foreign direct investment, including for the pharmaceutical biotechnology sector (Smith, 2002), there is no published analysis of the agricultural biotechnology and plant breeding sector, although Srinivasan (2004) did examine international flow of varieties using PVP data from UPOV.

With respect to understanding comparisons in IPR use across countries, Maskus (2006) proposes the use of revealed technology advantage, which corresponds to the revealed comparative advantage used in empirical trade analysis but with patents substituting for exports. Revealed technology advantage is thus measured as the share of a country's patents in a given technology field out of all global patents in that field, normalized by that country's share in all patents.[4] Concentrating on the Asia-Pacific region, Maskus (2006) illustrates that countries such as South Korea and China have a lower revealed technology advantage compared to countries such as the US and Japan, as would be expected. This may provide a rationale for maintaining more flexible IPR policies, though well-defined IPRs are still likely to be necessary for countries to encourage technology transfer. Maskus looks exclusively at patents, but his innovative measure could be of use for studying other IPRs.

There is considerable unexploited value in descriptive analysis of IPR data, particularly at an international level, to simply understand trends and inform more systematic analysis. Michiels and Koo (2008) examine patent data from the EPO to assess the development of Agrobacterium-mediated transformation technology and its diffusion. Examining data for three years (1996, 2000 and 2004), this study found evidence of a shift in research focus from fundamental to applied research, as well as a rise in applied crop research activity by emerging market countries, in particular China and India.

2.7 Critical assessment

The availability of formal IPRs for inventions in the realm of plant breeding and biotechnology has changed, generally in discrete intervals, as new forms of IPRs, plant patents and PVP, have been created and as utility patents have evolved through either regulation (as in the EU) or jurisprudence (as in the US). This demonstrates how the IP system shifts to accommodate changes in technology and economic development,

[4]Revealed comparative advantage is measured as a share of a country's exports of a particular class of goods out of global exports of those goods, divided by the country's total exports as a share of global exports. Values greater than one indicate that the country accounts for a greater share of global exports of that good than the country does for global exports of all goods.

while the underlying framework of excludability, as typified by patents, remains relatively stable, with PVP and plant patents representing, in effect, adapted forms of patent protection.

This chapter has attempted to illustrate some of the principal trends in the evolution of IPRs in agricultural biotechnology and plant breeding and the important research and policy questions it raises. Much of the research and analysis in this area has concentrated on how policy can improve the system of IPRs in order to maximize the rate of innovation. There are some indications, as suggested in the recent studies by Graff et al. (2009) and Lei et al. (2009) that the risk of an anticommons is a real concern in agricultural biotechnology. Agricultural research and technology development has generally been dominated by the efforts of public organizations. Growth in public funding has slowed in recent years and private sector actors have emerged in certain market segments. The effects of the increasing use of various proprietary rights in agricultural research on this complex web of actors, which accelerated in the 1980s and 1990s, are perhaps only now beginning to be seen. Given the challenges of meeting global food security challenges while reducing the environmental impacts of agriculture in the coming decades, these developments should be cause for concern.

Despite some exceptions, a relatively neglected area of research has concerned how the availability and use of IPRs affects the nature and direction that R&D programs take. For instance, the innovation pathway of genetic modification of crops for insect resistance and herbicide tolerance has delivered demonstrable economic, environmental, and social benefits, but other innovation pathways might have dominated under different policies. This may benefit from an additional set of methods than has been reviewed here, drawing more on the field of innovations systems analysis, a field which has given attention to historical trajectories and path dependency in other technology areas. Any research in this area will require improvements in metrics by which the direction of agricultural biotechnology research can be measured, as well as the necessary data collection and analysis. In this regard, plant breeding and agricultural biotechnology also needs to be seen within the broader context of innovation in agricultural systems, which comprises many more elements than the development of new crop varieties.

Also with respect to methods, there have been relatively few examples of multidisciplinary perspectives as called for by Kesan (2000). Legal research has tended to assess interpretations of law in light of technological developments, including possible adjustments in either legislation or jurisprudence. Economic research, which has been the primary focus of this chapter, has concentrated on understanding the effects of IP policy on outcomes in terms of innovation, market structure, and the distribution of benefits and costs. There has been little interaction between these areas of research.

Empirical research on the IP system and biotechnology in agriculture has concentrated on widely-grown grain and oilseed crops. These are indeed the crops that have seen the most cultivation of genetically modified varieties. There appears to be a different array of incentives and dynamics in the high value-added segment of horticultural crops, where biotechnology has become more prominent in the process of breeding, through sequencing and marker-assisted selection techniques. There is less prevalence of genetic modification, particularly as many of these crops are destined for either direct consumption ingestion by humans, but IPRs are still relevant to the breeding process.

Understanding the effects of the dynamic IP system could also benefit from more attention to research on licensing, exchange, enforcement and litigation of these patents. It is arguable that these aspects of the IP system have as much of an effect on the innovation process as legislation and regulations concerning the awarding of patents and their scope. Clearly this research presents both data and methodological challenges that would need to be addressed. Such data may need to be collected through survey methods.

3 IPRs for intermediate goods in an international context

3.1 Introduction

This chapter examines the tradeoffs involved in the scope or strength of intellectual property right (IPR) protection for an intermediate good. Most existing analyses of the level of appropriability consider the case of the scope of IPRs for a final consumption good, or the case of process innovations. The current paper develops a simple model involving monopolist innovation and production of a good that is then used to produce a final consumer good. Using a vertical product differentiation model, the amount of innovation in the intermediate good is endogenized and the good can be subject to IPR protection, most likely in the form of patents. The results offer some refinement to the tradeoffs between innovation and diffusion arising from the extent of IPRs seen in the case of consumer goods. Specifically, consumers as a whole may benefit from moderate levels of appropriability if this leads to greater production and lower prices of the final consumption good. An extension to a two country setting with trade highlights the differing interests between countries that are technology producers and those needing to purchase or license.

The motivation for this analysis is the agricultural seed sector, in which IPR protection has been a subject of considerable political controversy. IPR provisions for agricultural plant varieties were developed in industrialised countries during the twentieth century to provide incentives for private sector plant breeders. In most cases, governments opted for plant variety protection (PVP)[1], a specialized form of IPR that is more limited in scope than patents available, for example, for industrial innovations. In general, PVP allows breeders to restrict the commercial production and sale of an improved variety, provided that a number of conditions are satisfied.[2] In some instances, further restrictions may be granted concerning the use of the variety in breeding programs or the use of progeny (second generation seed), but the general lack of such restrictions makes PVP similar to copyright, as much as to patents. In the case of the latter, the use of a patented innovation by others in commercially oriented R&D requires permission of the patent holder. PVP protection, on the other hand, contains a "breeder's exemption" which explicitly allows for the use of protected plant varieties by competitors in their breeding programs.

[1] Plant varietal protection (PVP) is also referred to by the legal concept of 'plant breeders' rights' (PBR)

[2] These conditions usually comprise the genetic characteristics of Distinctness, Uniformity and Stability, thus DUS(see, for example, Leskien and Flitner, 1997; Ghijsen, 1998).

Industrialised countries introduced their PVP legislation at different stages but most are now members of the International Union for the Protection of New Varieties of Plants (UPOV). UPOV is in effect a treaty which defines specific provisions of PVP legislation which signatories agree to incorporate in their legislation. Two acts of the UPOV treaty exist: UPOV (1978) and UPOV (1991). The 1991 Act increased the scope of protection that members were required to provide, including exclusive rights for the right holder on the import and export of a protected variety. The newer version also requires the possibility of restricting the use of farm-saved seed.[3] The analysis in this chapter can be seen as concentrating primarily on restrictions on the use of farm-saved seed or unlicensed commercial sale of a protected variety. This is one of two characteristic, though distinct, appropriability issues in the plant breeding sector. The other is the extent to which competing breeders are permitted or able to use each other's innovations in their subsequent breeding efforts (the breeder's exemption). That issue is not addressed in this chapter though the literature review discusses relevant papers.

The current paper adds to the existing literature on the farmer's rights (or piracy) issue of appropriability by endogenizing the innovation decision in a vertical product differentiation framework, by explicitly accounting for farm seed as an intermediate good, and by extending the analysis to a two country setting. Considering the innovation good to be an intermediate one used in the production of a homogeneous final consumer good introduces an interdependence among farms, which can be seen as similar in general nature to network externalities among consumers of competing goods with one important difference. Consumers' utility from consuming a good increases with the number of consumers purchasing and using the same good (see, for example, Lambertini and Orsini, 2005). On the other hand, firms purchasing an intermediate good and competing in a final product market benefit from fewer firms competing with them.

3.2 Literature review

The economic literature on IPRs has evolved from an analysis of a simple discrete case of fully enforceable exclusive rights (Arrow, 1959) to an examination of various dimensions of appropriability provided through either legislation or enforcement and litigation. A general theme in this literature is that of a tradeoff between the dynamic incentives to innovate and the extent of diffusion or benefits enjoyed by consumers (Scotchmer, 2004). One aspect of appropriability that has been analysed in considerable detail is that of the scope of protection offered, which refers to what is eligible for protection and which activities this protection restricts. Such concepts are elaborated and analyzed by O'Donoghue et al. (1998). This partial equilibrum literature is fairly distinct from general equilibrium approaches, in which the details of IPR policy and

[3]The 1991 Act does also introduce some possible limitations on the breeder's exemption to address the case "essentially derived varieties" though this has had little impact to date due to difficulties in implementing the associated concept.

implementation must necessarily be simplified. Examples of the latter include Aghion and Howitt (1998); Aghion et al. (2001); O'Donoghue and Zweimuller (2004).

Another literature has examined the incentives and tradeoffs for developing countries to introduce IPR protection, particularly since the negotiation of the TRIPS Agreement. In an earlier general equilibrium setting with homogeneous agents, Helpman (1993) illustrates the channels by which increased IPR protection affects two regions, North and South. In his model, the South has little or no incentive to increase IPR protection if it imitates technological innovations developed in the North, even if this leads to more foreign direct investment and technology transfer. Lai and Qiu (2003) also examine the issue of differential standards in IPR protection between the North and South in a multi-sector model with homogeneous agents. They find though that there can be net gains to global welfare from a harmonization of the South's level of protection with that of the North, if there are sufficient gains from trade to be earned through associated lowering of the North's import tariffs. This is intended to capture the essence of the bargain made in the Uruguay Round with its inclusion of the TRIPS Agreement; developing countries agreed to this provision as part of a package deal in which greater market access was granted.

The vertical product differentiation model, developed originally by Mussa and Rosen (1978), and further extended by Shaked and Sutton (1982), has also been used to analyze incentives to invest in quality interpreting that as innovation. In a major contribution to this stream of literature, Motta (1993) examined the overall welfare effects of Bertrand vs Cournot competition when the investment in quality is endogenized. Aoki and Prusa (1997) analyzed how the timing of investment affects quality and related this to application process for patents. Extensions of the framework to a multi-market or two country setting and an analysis of trade policy, including technical standards, include papers by van Dijk (1995), Boom (1995), Motta et al. (1997), Cabrales and Motta (2001), Zhou et al. (2002), Toshimitsu (2003), Boccard and Wauthy (2005, 2006), Oladi et al. (2008), and Valletti (2006), who examines monopolist pricing in several market segments defined internationally.

Incorporating the extent of appropriability arising from IPR policy to the vertical product differentiation model arose in the context of copyright protection and piracy of software. Bae and Choi (2006) proposed a model with one innovator and one pirate competing in prices, with the pirate's quality constrained by a parameter reflecting possibly technical limitations to copying the protected product or IPR policy restrictions, including the likelihood of infringement being detected and legal action undertaken. They refine the traditional tradeoff between dynamic and static effects by allowing IPR policy to also affect the cost of copying a protected product which can reduce the dynamic incentives to innovate by reducing the potential market for the monopolist.

More recent papers by Choi et al. (2010) and Belleflamme and Picard (2007) extend the analysis to a duopoly in which two innovators are competing not only against each other, but also pirates. The analysis in the current paper builds on this model of piracy as this represents well the nature of the IP protection issue facing breeders seeking to reduce illegal reproduction of their seed, or similarly policy options to render illegal such reproduction by farmers. Compared to the line of literature based on duopoly models, the single innovator situation changes the competition in quality to a Stackelberg situation. The lower quality producer is constrained to produce a certain quality level (the copy) according to the extent of IP protection, but does not have to invest in developing this.

In a review article in the mid-1990s, Lesser (1997) indicated that there had been relatively few attempts to model PBRs as an explicit form of IPR. The subsequent expansion in the diffusion of genetically modified crops and increasing relevance of patent protection for the breeding sector, in addition to PVP, has stimulated further theoretical development in the literature. The vertical product differentiation model has recently been applied to the agricultural plant breeding and biotechnology sector by Fulton and Giannakas (2004), Plastina and Giannakas (2007), Giannakas and Yiannaka (2008). These papers have analyzed the market and welfare effects of the introduction of genetically modified crops, including the effects of segregation and labeling policies, but have not endogenized the decision to invest in quality. This issue has been formally analyzed by Moschini and Lapan (1997). Yerokhin and Moschini (2008) develop a duopoly R&D model of plant breeding to examine the effects of the breeder's exemption on strategic behaviour between two innovators. Alston and Venner (2002) do incorporate partial appropriability into their model developed for U.S. PVP situation, but do not include competition from other sources of seed or the interdepedence between farms producing for a final output market. Van Tongeren and Eaton (2004) extended the model of Alston and Venner (2002) to a two country setting, illustrating that lower appropriability in a second weaker market could be welfare enhancing due to the benefits of third degree price discrimination.

Heisey and Brennan (1991) developed a model of incentives at the (representative) farm level to purchase seed more frequently rather than to produce seed from last year's existing crop. They did not however consider the effect of possible legal restrictions on such activity, as their analysis was motivated by the productivity benefits of diffusing modern varieties to farmers in developing countries.

A paper that is similar in aim to the current one is by Burton et al. (2005). They develop a model to analyze the competition that breeders face from piracy and compare legal protection options in the form of contracts with farmers to technical protection in the form of genetic modification that prevents plant from producing fertile seeds.[4] Ambec et al. (2008) also examine the incentives to reduce the reproducability of seed (a form of durable good) but do not address the incentive to invest in innovation.

[4]Such technologies, which have yet to be developed to commercial viability, are generally known as genetic use restriction technologies (GURTs).

3.3 Model

3.3.1 An intermediate good with a monopoly innovator

The analysis is based on a simple model of vertical product differentiation, but in which farms instead of consumers are differentiated. The vertical product differentiation model is typically applied to situations where final consumption goods differ in some quality attribute which affect consumers' utility. The framework can also plausibly be extended to the situation of intermediate production goods. In the analysis presented here, this good is seed (or planting material) that is sold to farmers. This difference can be interpreted as their varying capacity of farmers to profit from higher quality seed, which can be due to a range of physical and human factors, including differences in agro-ecosystems and quality of land resources, farmers' knowledge and technical capabilities, or access to financial and physical capital. The agricultural sector lends itself to this interpretation as it is generally composed of a large number of small, heterogeneous firms (farms), producing relatively homogeneous products in a competitive setting.

Farms are distributed uniformly along a continuum $[0, \bar{\theta}\,]$.[5] It is assumed that each farmer purchases one unit of the seed if positive profits can be earned, $g\theta u - p > 0$, where u and p are, respectively, the quality level and price of the seed and g is the price earned for farm output. If net farm profits are zero or less, the farm purchases no seed, and does not produce.

The innovator/seed producer make two profit-maximizing decisions sequentially.[6] First, they must choose a level of quality u, with an associated cost function of $C(u)$. Secondly, the seed producer sets the price, p. The choice of quality level is often interpreted as an R&D investment decision (Motta, 1993). The analysis here assumes in the first instance a simple quadratic function, $ru^2/2$, with r a scaling factor. For simplicity, production costs of seed are assumed to be zero, as interest focuses on the investment decision.

The simplest version of the model examines the situation of a monopolist innovator, (denoted with subscript 1), who faces competition from "piracy", unauthorized production and sale of its product, indexed by c. The pirated seed differs in quality from the original according to a parameter $\delta \in (0, 1)$. As $\delta \to 0$ then the pirated seed does not differ from the original at all, and at the other extreme as $\delta \to 1$, the copied seed would effectively be of zero quality. We interpret δ as a measure of appropriability of the research innovations embodied in the quality of the seed. In particular, the degree of appropriability represents a constraint, due to the (partial) granting or enforcement of intellectual property rights, on the ability of the pirate

[5] Some earlier versions of the vertical product differentiation model assumed that the market was completely covered; Wauthy (1996) has generalized this class of models to allow for endogenous determination of market coverage. Note that Bae and Choi (2006) do not assume a specific distribution, which is a potential generalization discussed below in the conclusions.

[6] The sequential nature is not necessary in the first analysis of the model but is introduced now as it will be used in the extension to a two country setting.

to reproduce the same plant variety or to charge the same price. These IPRs could include plant breeder's rights, or also patent, trademark or trade secret protection. In addition to the legal interpretation, appropriability could reflect biological/technical factors which result in deterioration in the quality of the reproduced seed. This is quite common in the case of hybrid seeds, the progeny of which farmers may try to save and replant, a practice quite common in many developing countries. But even in the case of open-pollinated varieties (OPV), there may be a loss of quality in copies or subsequent generation seed due for example to fewer efforts devoted to sorting and treating seed.

Each farm (indexed by θ) chooses between purchasing the bona fide seed with quality u at price p_1, or the copy with quality $(1-\delta)u$ at a constant price c, with profits respectively of $g\theta u - p_1$ and $g\theta(1-\delta)u - c$. Note that the copied seed could also be produced by the farm itself, which would also require the use of farm resources or can be thought of as the opportunity cost of not selling such seed to other farms. There are therefore effectively no barriers to producing the copied seed and thus no profits to be made.[7]

The solution method proceeds backwards by first solving for price and then the quality investment decision of the monopolist seed producer. To solve the price decision, denote by θ_1 the farm which is indifferent between purchasing the original seed from the monopolist and the pirated seed, which implies that $g\theta_1 u - p_1 = g\theta_1(1-\delta)u - c$, or $\theta_1 = (p_1 - c)/g\delta u$. The range of farms choosing for the monopolist's seed, $(\bar{\theta} - \theta_1)$, increases with lower prices (p_1), with higher prices for copied seed (c), for higher values of the output price (g), higher levels of quality of the seed (u), or higher levels of appropriability of the benefits of innovation (δ). Similarly, the farm which is indifferent between purchasing lower quality pirated seed and not producing at all, denoted by θ_c, is found by solving $g\theta_c(1-\delta)u - c = 0$, or $\theta_c = c/(1-\delta)gu$. The range of farms choosing pirated seed, $(\theta_1 - \theta_c)$, decreases with increases in the price of this seed (c), but the relationship with output price and quality depends on the interaction in the pricing decisions of the monopolist and the pirate(s). Higher levels of appropriability (δ) will however also decrease the range of farms choosing pirated seed, by raising θ_c in addition to lowering θ_1.

Recalling that each farm produces one unit of output, total supply in the final goods market is simply the number of farms producing, given by $(\bar{\theta} - \theta_c)S$, where S is the mass of farms.[8] Demand is assumed to be unitary elastic: b/g. Substituting in the expression above for θ_c, and equilibrating demand and supply leads to the following solution for farm product price g:

$$\frac{b}{g} = S\left[\bar{\theta} - \frac{c}{(1-\delta)gu}\right], \text{ or}$$

[7] This differs from most other models of piracy in the production of consumer goods, which assume certain barriers to piracy and thus prices for the pirated good that may exceed marginal cost (as in Bai and Choi 2006).

[8] Although S is not essential for deriving the results for a single country, we introduce it now as it will play a more important role in the context of two countries.

$$g = \frac{b(1-\delta)u + Sc}{S\bar{\theta}(1-\delta)u}. \tag{3.1}$$

Expressions for the indifferent farms, θ_1, θ_c, can then be derived substituting for g:

$$\theta_1 = \frac{S\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}, \quad \theta_c = \frac{S\bar{\theta}c}{[b(1-\delta)u + Sc]}. \tag{3.2}$$

Total quantity of monopolist seed and pirated seed can then be derived in terms of p_1:

$$q_1 = S(\bar{\theta} - \theta_1) = S\bar{\theta} - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}$$

$$q_c = S(\theta_1 - \theta_c) = \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]} - \frac{S^2\bar{\theta}c}{[b(1-\delta)u + Sc]}.$$

Given a quality level, u, the monopolist set its price to maximize profits, taking into account effects in the final good market. Note that the monopolist also incurs the same cost of producing seed, c:

$$\begin{aligned} \Pi_1 &= (p_1 - c)q_1 = (p_1 - c)\left[S\bar{\theta} - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}\right] \\ &= S\bar{\theta}(p_1 - c) - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)^2}{\delta[b(1-\delta)u + Sc]} \end{aligned}$$

Maximizing Π_1 with respect to p_1 implies

$$S\bar{\theta} = \frac{2S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]} \;\Rightarrow\; p_1 = \frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)} + c \tag{3.3}$$

which expresses p_1 as the monopolist's production cost plus a markup, which corresponds to $\delta gu\bar{\theta}/2$. Note that p_1 charged by the monopolist increases with both higher quality, u, and greater appropriability, δ, which is intuitive. This leads to the following solutions for θ_1, q_1:

$$
\begin{aligned}
\theta_1 &= \frac{S\bar{\theta}(1-\delta)(p_1-c)}{\delta[b(1-\delta)u+Sc]} \\
&= \frac{S\bar{\theta}(1-\delta)}{\delta[b(1-\delta)u+Sc]} \cdot \left[\frac{\delta[b(1-\delta)u+Sc]}{2S(1-\delta)}\right] \\
&= \frac{\bar{\theta}}{2} \qquad (3.4) \\
q_1 &= S(\bar{\theta}-\theta_1) \\
&= S\,\frac{\bar{\theta}}{2}\,.
\end{aligned}
$$

The finding that the monopolist will serve a fixed portion of the market, in absence of competition, is found in the original result by Mussa and Rosen (1978). This relatively simple structure of the model also means that the proportion of the market served by copied seed, is also not dependent on the monopolist's price:

$$
\begin{aligned}
q_c &= S(\theta_1-\theta_c) \\
&= S\left[\frac{\bar{\theta}}{2} - \frac{S\bar{\theta}c}{[b(1-\delta)u+Sc]}\right] \\
&= S\left[\frac{\bar{\theta}[b(1-\delta)u+Sc]-2S\bar{\theta}c}{2[b(1-\delta)u+Sc]}\right] \\
&= \frac{S\bar{\theta}}{2}\left[\frac{[b(1-\delta)u-Sc]}{[b(1-\delta)u+Sc]}\right]
\end{aligned}
$$

Proposition 1: The level of quality offered and the profits earned by the monopolist are maximized with a maximum level of appropriability.

The monopolist's decision to invest in quality is solved by maximizing the full profit function with respect to u, including the cost r of investment in addition to profits from selling seed is

$$
\begin{aligned}
\pi_1 &= (p_1-c)q_1 - \frac{ru^2}{2} \\
&= \frac{\delta[b(1-\delta)u+Sc]}{2S(1-\delta)} \cdot S\frac{\bar{\theta}}{2} - \frac{ru^2}{2} \\
&= \frac{\delta\bar{\theta}}{4}\left(bu + \frac{Sc}{1-\delta}\right) - \frac{ru^2}{2} \qquad (3.5)
\end{aligned}
$$

$$
\frac{\partial \pi_1}{\partial u} = 0 \;\Rightarrow u = \frac{\delta\bar{\theta}b}{4r}. \qquad (3.6)
$$

The monopolist's price can then be rewritten as

$$\begin{aligned} p_1 &= \frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)} \\ &= \frac{\delta c}{2(1-\delta)} + \frac{\delta^2 b^2 \bar{\theta}}{8Sr} + c\,. \end{aligned} \tag{3.7}$$

Thus as intuition would suggest, the level of quality (or innovation) increases with the strength of final demand (b) and also appropriability (δ), but decreases with the cost of innovation (r). Quality is not directly determined by the cost of producing or copying. Substituting this solution back into the monopolist's full profit function, we find that

$$\pi_1 = \frac{\delta^2 \bar{\theta}^2 b^2}{32r} + \frac{\bar{\theta} Sc}{4(1-\delta)}$$

and so profits are increasing in δ, as might be expected.

Proposition 2: Total profits of farms purchasing from the monopolist are maximized with maximum appropriability.

This is proven by maximizing the expression for profits for these farms with respect to δ, which always occurs at the maximal value of $\delta = 1$ (see sec. 3.5). The simple intuition is that maximum appropriability effectively eliminates competition for farms in the final product market from those farms producing copied seed. Higher appropriability allows the monopolist to charge a higher price for the seed, but farms are able to pass on these increases given the perfectly elastic demand specified for the product market. As noted above, one feature of this specification is that the proportion of farms purchasing the monopolist's seed remains constant. In markets with a limit price for the final good, then a decreasing proportion of farms would find it profitable to produce as the price of the input keeps rising. For now, we note that this stylized situation can be interpreted as representing the agricultural sector as a whole, as opposed to a single sector, with demand for food output being relatively inelastic over the long term.

Proposition 3: Profits for farms using copied seed could be maximized at the moderate level of appropriability $\delta = 1/2$ provided the strength of demand for the farm's product sufficiently exceeds the cost of producing seed.

The proof is found in the sec. 3.5 and is also obtained by maximizing the respective expression for total farm profits. The result of $\delta = 1/2$ is obtained provided that the strength of demand for the final product is sufficiently larger, in relative terms, than the cost of producing and copying seed, which seems acceptable. As a whole, farms using copied seed do not therefore achieve maximum total profits with no appropriability at all ($\delta = 0$), since there is then no incentive for the innovator to invest in quality. At very low levels of appropriability, the quality is so low that very few farms are able to produce profitably using copied seed. Further increases in appropriability at this low level, only partially offset the ability of farms to use this seed. However once appropriability has reached a higher level, it dominates the increases in quality that it stimulates, and the number of farms being able to produce profitably with copied seed starts to decline. As shown in the Annex, the range of values for δ, centred around $\delta = 1/2$, for which total profits exceed those at minimum or maximum appropriability rises as the ratio between final demand and cost of the input increases.

Proposition 4: Consumers benefit most from a moderate level of appropriability, set at $\delta = 1/2$.

The proof is found in sec. 3.5.3 and is obtained by minimizing the expression for consumer's price, g, with respect to δ (after substituting for u, using (3.6)):

$$g = \frac{b}{S\bar{\theta}} + \frac{4cr}{\delta(1-\delta)b\bar{\theta}^2}\,. \tag{3.8}$$

Thus consumers also benefit most from having a moderate level of appropriability. This is a static view though based on the price for the consumer good, in this case food that is characterized as an essential good with an infinitely elastic demand. A moderate level of appropriability maximizes farm production. In this model, this requires that as many farms are able to use or purchase copied seed, since the number of farms using seed purchased from the monopolist is fixed ($\bar{\theta}/2$) and thus production from those farms is also fixed. This does not correspond to a maximum level of appropriability which maximizes innovation or investment in quality (as can be seen from (3.6)). As appropriability increases beyond moderate levels, the increased investment in quality is not available to as many farms using copied seed, and only results in increased profits for farms purchasing seed, not in increased production. This reflects the assumptions of the model: each farm produces either one unit of final product or not at all, and also the parametrization of the demand function for farm product. If quality of seed led to greater farm output, then increased appropriability, and thus quality, might also benefit consumers. Nonetheless, this model illustrates how there can be a tradeoff between quality and consumer welfare. It is also worth pointing out that, while this model represents essentially a static situation, a dynamic perspective might also suggest that consumers would benefit in the long run from greater innovation.

The analysis highlights how the decision for policy makers setting the level of appropriability can involve tradeoffs, particularly as there may be multiple policy objectives. In terms of social welfare, as measured by profits of the monopolist and farms, in addition to consumers' surplus, the optimal level of appropriability would be somewhere between the moderate level ($\delta = 1/2$) that most benefits consumers and also farms using copied seed, and the maximum level ($\delta \to 1$) that most benefits the monopolist and its client farms. In terms of the agricultural setting considered in this analysis, a moderate level of appropriability could also be the optimal policy from a food security perspective, as it ensures the lowest price for food. If though policy takes an agricultural sector perspective and seeks to maximize profits in the sector, the optimal level of appropriability would be the maximum available. On the other hand, policy also needs to take account of differential effects among farms by seeking to ensure profitability for less well-endowed or productive farm businesses (perhaps from a social equity perspective), then a more moderate level of appropriability would again be favored.

In general, these features of the model capture the essential characteristics of the agricultural and plant breeding sector in recent decades. Through revisions to UPOV (1991 Act, as well as ongoing discussions among UPOV members and the breeding industry) and also increasing applicability in different jurisdictions of patent protection for plant varieties, or the biotechnological constructs contained in them, appropriability has been increasing. This has revealed differing interests among farms, with those generally most able to profit from improved innovations being supportive. But other farmers have voiced opposition and also committed acts of infringement on the use of protected seeds. Consumers have not been as active in this debates and discussions, except with regards to the introduction of genetically modified crops. For consumers as a whole, any resulting improvements in productivity of agricultural production have not necessarily translated into reduced prices for food products.[9] So consumers are arguably not yet appreciating any benefits of possibly accelerated innovation resulting from higher appropriability. It could be argued that more time is needed for these incentives to influence research and development in plant breeding, and to result in commercialized products. But the consumer perspective is complicated. Many consumers are suspicious of possible health and environmental risks associated with genetic modification. Interestingly though, many appear also to have ethical concerns related to increasing levels of appropriability - concerns that are not related to possible price effects. It should also be noted that any price effects may be difficult to discern given larger trends in the past two decades towards increasing prices for basic foodstuffs, driven largely at a global level by growing demand from emerging economies (see, for example, Koning and Mol, 2009).

3.3.2 Extension to two countries

The analysis is now extended to a situation involving two countries. It is assumed that innovation takes place in the North (N) and that now the monopolist can also market this in the South (S), but must also compete against unauthorized copying and sale of the seed. First the relatively simple situation of autarky is considered, in which there is no trade in the farm product, and then it is seen how the solutions will change if international trade in the farm product also takes place.

In general, due to lower incomes, the strength of demand for the final farm product is expected to be lower in the South than in the North: $b_S < b_N$. In terms of the farm sector, the South is assumed to consist of a larger mass of farms ($S_S > S_N$). Although the most productive farm in the South, indexed by $\bar{\theta}_S$, could be more or less productive than that of the North ($\bar{\theta}_S \lesseqgtr \bar{\theta}_N$), in general the analysis restricts

[9]Note though that in developed countries, the production price of agricultural crops is a small proportion of the final consumer price of food staples, with transport, processing and marketing generally accounting for a larger share.

itself for reasons of simplicity to considering that the distributions are identical. The monopolist is based in the North.

The analysis is relatively short-term in that the level of innovation, as represented by u, is taken as exogenous to the opening of trade in either seeds or the final product. It would be expected that the opportunity to serve the market in the South would, in time, influence the decision by the monopolist innovator as to the amount of investment and thus the level of quality. Introducing this longer term consideration would entail multiple equilibria (indeed an infinite number given the continuous nature of the decision to invest in quality).

Regarding sequencing of policy decisions, the North first determines its own level of appropriability through IPR policy (δ_N) in both cases. The South takes this as given and then determines its own level of appropriability (δ_S). This can be considered as representing a situation prior to TRIPS. Then the situation is examined in which the South is required, by international agreement, to raise its level of appropriability with that of the North. This could be due to multilateral agreements such as TRIPS, or regional or bilateral trade agreements. As with the Uruguay Round and the creation of both the WTO and TRIPS, this represents a negotiated outcome in which the South hopes to gain increased access to markets of the North, but must agree to TRIPS as part of the overall deal. Together with the assumption that the innovator bases its investment decision only on the market in the North, the analysis below can best be seen as representing the post-TRIPS short-run situation. This is not to argue that the longer term effects are not as important, if not more so; however, the insights generated are relevant for explaining the policy and public debates that have taken place around the adoption of TRIPS.

3.3.2.1 Autarky in the final product

In the simplest situation, the North determines its own level of appropriability as above, which leads to decisions by the monopolist for innovation in quality as seen in the previous analysis. The South then takes the level of quality, u, as given and determines its own level of appropriability, δ_S, where the subscript S now denotes the South. Starting with the final product market, equilibrium is characterized as in (3.8):

$$g_S = \frac{b_S(1-\delta_S)u + S_S p_{cS}}{S_S\bar{\theta}_S(1-\delta_S)u} \ . \tag{3.9}$$

where

$$u = \frac{\delta_N \bar{\theta}_N b_N}{4r}, \tag{3.10}$$

inserting subscripts N for North (except for the cost of investing in quality, r for which there is only one value).[10] Then the price in the South and the North can be written as follows:

$$\begin{aligned} g_S &= \frac{b_S}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)u} = \frac{b_S}{S_S\bar{\theta}_S} + \frac{4cr}{\delta_N(1-\delta_S)b_N\bar{\theta}_S\bar{\theta}_N} \\ g_N &= \frac{b_N}{S_N\bar{\theta}_N} + \frac{c}{\bar{\theta}_N(1-\delta_N)u} = \frac{b_N}{S_N\bar{\theta}_N} + \frac{4cr}{\delta_N(1-\delta_N)b_N\bar{\theta}_N^2} \, . \end{aligned}$$

From this it can be seen that if demand is weaker in the South ($b_S < b_N$) and if appropriability in the South is no stronger than that of the North ($\delta_S \leq \delta_N$), then the price of the final product will be lower in the South ($g_S < g_N$).

The monopolist incorporates the final product price into the determination of its seed price:

$$p_{1S} = \frac{\delta_S[b_S(1-\delta_S)u + S_S c]}{2S_S(1-\delta_S)} + c \tag{3.11}$$

and thus undertakes price discrimination between the northern and southern markets. As in the initial analysis above, the values for the cutoff farms, defining the size of the monopolist's market and the market for copied seed, respectively are:

$$\theta_{1S} = \frac{\bar{\theta}_S}{2} \text{ and } \theta_{cS} = \frac{S_S\bar{\theta}_S c}{[b_S(1-\delta_S)u + S_S c]} \, .$$

Note that this model does not predict that monopolist will increase export of seeds to South as the latter increases its appropriability. This is due to the specification of the model with a fixed share of the market served by the monopolist. It is possible to conceive that the market in South is served only by traditional seed varieties prior to the monopolist entering the market, which also leads to the availability of seed copies. This is however clearly unsatisfactory and it would be preferable if the share of the market in the South, given a fixed quality, were directly related to the level of appropriability available; in other words that θ_{1S} were decreasing in δ_S. Again, this arises from the assumption of fixed output per farm and the specification of an infinitely elastic demand for the final product. Nonetheless we proceed to examine how the interests of different actors (monopolist, farms and consumers) are related to the level of appropriability offered.

Proposition 5: The additional profits for the monopolist from marketing seed in the South are maximized with a maximum level of appropriability feasible.

[10] Since u is determined entirely by the circumstances in the North, in some of the derivations below, it is maintained as a variable for ease of interpretation.

As in the single country case, the monopolist profits from selling additional seed in the South (see (3.5)),

$$\pi_{1S} = \frac{\delta_S \bar{\theta}_S}{4} \left(b_S u + \frac{S_S c}{1 - \delta_S} \right)$$

can be easily seen to be increasing in δ_S.

Proposition 6: Total profits of farms in the South purchasing the monopolist's seed are maximized with a maximum level of appropriability that is feasible.

The proof is given in sec. 3.5.4. The intuition is that maximal appropriability allows these farmers purchasing the monopolist's seed to capture all of the market in the South, and they are still able to pass on high prices they pay to the monopolist for seed to the consumer in the form of a higher price for farm product.

Proposition 7: Under autarky, total profits for farms in the South using copied seed will be maximized with a minimal level of appropriability if the strength of demand sufficiently exceeds the cost of producing seed.

The results is shown in sec. 3.5.5. As in the situation for the North, this means that if the strength of demand is sufficiently strong relative to the cost of producing seed, then the total profits earned by farms using copied seed will be maximized with little or no appropriability. Note also that this implies maximum diffusion of the innovation, in the form of copied seed, in the South. Otherwise, profits will be maximized at a maximal level of appropriability, and somewhat counter-intuitively, enjoyed by a very limited number of farms.

Proposition 8: Under autarky, consumers in the South benefit from a minimal level of appropriability.

Recalling (3.8), the price for consumers in the South is simply

$$g_S = \frac{b_S}{S_S \bar{\theta}_S} + \frac{c}{(1 - \delta_S) u} \tag{3.12}$$

and ${}^{\mathrm{d}g_S}/_{\mathrm{d}\delta_S} > 0$; so price in the South is minimized with $\delta_S \to 0$. The lowest level of appropriability maximizes the number of farmers producing in the South (θ_{cS} is also increasing in δ_S; see (3.2)) and thus the price of farm output.

In summary, under autarky there are different interests in the second country concerning the level of IPR protection that are somewhat similar to those in the single country case. The monopolist and the most productive farms benefit from maximal levels of appropriability. Less productive farms, on the other hand, could benefit most from a minimal level of productivity, under conditions of sufficiently strong demand for farm product relative to costs, which would also maximize the diffusion of the innovative seed. For this reason, consumers would also benefit most from minimal appropriability, and thus have interests essentially opposite to those of the monopolist and the more productive farms. This corresponds to restricting attention to the static situation examined in the single country case, where the effect of appropriability on innovation is ignored. It has here been assumed that the monopolist has based the investment decision only on the market situation in the North, and is now marketing this product in the South. Under these circumstances, if the South initially has a minimal level of appropriability, then any increase, as induced say by implementation of TRIPS, serves to increase the profits of the Northern monopolist but also the most productive part of the farm sector. On the other hand, consumers would be penalized through higher prices. Agreements on IPR protection, such as TRIPS, are also generally accompanied by measures to liberalize trade, as in the Uruguay Accord establishing the WTO in general, and the analysis now turns to how trade might affect these results.

3.3.2.2 Trade in the final product

The assumptions of the previous section concerning the weaker demand in the South ($b_S < b_N$), but with a larger mass of producers ($S_S > S_N$), are maintained.[11] When trade takes place in the final product, then its price will converge between North and South, leading to a new world price, g_W with $g_S < g_W < g_N$ and where

$$g_W = \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{u}\left(\frac{1}{1-\delta_N} + \frac{1}{1-\delta_S}\right)\right] . \tag{3.13}$$

If the situation is still as in the previous section under autarky, with u fixed, then the only way that production can adjust to trade is for it to decrease in the North and to increase in the South. Given the assumptions and specification of the model, this implies that θ_{cN} increases, while θ_{cS} increases (as confirmed below), and so the change in production is undertaken by a reduction in the North of the number of farms producing with copied seed, and an increase of such farms in the South.

Proposition 9: Given weaker final product demand and/or a larger mass of farms in the South relative to the North, opening to trade in the final product market will decrease the profits of farms in the North producing with purchased seed and increase the profits of such farms in the South.

[11] And $\bar{\theta}_S = \bar{\theta}_N$.

From 3.15, profits for farms producing with purchased seed can be derived more simply, maintaining g_i, $(i = N, S)$ as follows:

$$\begin{aligned}
\tau_{1i} &= \int_{\theta_{1i}}^{\bar{\theta}_i} (g_i \theta u - p_{1i}) \, \mathrm{d}\theta \\
&= \left[\frac{g_i u}{2} \theta^2 - p_{1i} \theta \right]_{\theta_{1i}}^{\bar{\theta}_i} \\
&= \frac{g_i u}{2} \left[\bar{\theta}_i^2 - \frac{\bar{\theta}_i^2}{4} \right] - p_{1i} \frac{\bar{\theta}_1}{2} \\
&= \frac{3}{8} g_i u \bar{\theta}_i^2 - \frac{1}{4} g_i \delta_i u \bar{\theta}_i - \frac{c}{2} \\
&= \frac{g_i u \bar{\theta}_i}{4} \left(\frac{3}{2} \bar{\theta}_i - \delta_i \right) - \frac{c}{2} \,. \qquad (3.14)
\end{aligned}$$

This is increasing in g. So if g_N decreases in the opening to trade to g_W, then τ_{1N} decreases. Similarly, if g_S increases to g_W, then τ_{1N} increases.[12]

Proposition 10: Given weaker final product demand and/or a larger mass of farms in the South, opening to trade in the final product market will lead to lower overall profits for farms in the North producing with copied seed, and higher overall profits for such farms in the South, provided that the strength of demand in each market is sufficiently strong relative to the cost of producing seed.

The proof in sec. 3.5.6 shows that if the strength of demand sufficiently exceeds the cost of producing seed, then the profits of farms using copied seed increase in final product demand. So if trade leads to a world price, g_W, lower than the price in the North under autarky, g_N, then farms using copied seed in the North lose from trade, and conversely for farms in the South using copied seed.

The analysis indicates that opening to trade in the final good could increase the political pressure from the agricultural sector in the North on the South for the latter to strengthen its IPR protection. In terms of the different interest groups in the North, this would clearly benefit the monopolist, and it would also be in the interests of farms in the North, including those purchasing seed as well as those using copied seed. An increase in appropriability in the South would partly redress the losses of farms in the North from the opening of trade, by reducing production in the South and thus increasing the world price for the farm product. To see that production in the South would be reduced, recall that, under trade, production in the South is

[12] Note that in 3.14 we see δ is negatively related to farm profits, which seems counter-intuitive to the result above that increased appropriability increases farm profits (for those purchasing seed). As g_i is being kept in the derivation, δ_i reflects only the effect of increased appropriability on higher prices that the farms must pay for purchasing seed. But this is easily passed on to consumers in the specification of final demand chosen here. Farms end up benefiting more through the effects of higher appropriability on g_i. This does indicate though that the results do depend considerably on the nature of the demand function chosen.

determined by

$$\theta_{cS} = \frac{c}{(1-\delta_S)g_W u} \text{ and}$$

$$\begin{aligned}
\frac{\partial \theta_{cS}}{\partial \delta_S} &= \frac{c}{u}\left(\frac{1}{(1-\delta_S)^2 g_W} - \frac{\partial g_W/\partial \delta_S}{(1-\delta_S)g_W^2}\right) \\
&= \frac{c}{(1-\delta_S)g_W u}\left(\frac{1}{(1-\delta_S)} - \frac{\partial g_W/\partial \delta_S}{g_W}\right) .
\end{aligned}$$

The sign of this derivative is determined by

$$\begin{aligned}
& g_W - (1-\delta_S)\frac{\partial g_W}{\partial \delta_S} \\
= \; & g_W - \frac{c}{(S_N\bar{\theta}_N + S_S\bar{\theta}_S)(1-\delta_S)u} \\
= \; & \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{u}\left(\frac{1}{1-\delta_N} + \frac{1}{1-\delta_S}\right)\right] - \frac{c}{u(S_N\bar{\theta}_N + S_S\bar{\theta}_S)}\left(\frac{1}{1-\delta_S}\right) \\
= \; & \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{(1-\delta_N)u}\right] \\
> \; & 0 .
\end{aligned}$$

So $\partial\theta_{cS}/\partial\delta_S > 0$ and thus an increase in appropriability in the South, following on the opening of trade, will always reduce the number of farms in the South producing with copied seed, thus reducing production. On the other hand, farms in the South purchasing the monopolist's seed will benefit from higher appropriability through the higher global price, as was shown above under the autarky situation, even though they will have to pay a higher seed price. Consumers in both the North and the South will though have to pay a higher price and will therefore not be in favor of increasing appropriability in the South.

These differing interests in IPR policy in the model correspond to what has been witnessed with the introduction of TRIPS in the agricultural sector. Resistance or opposition to implementing TRIPS obligations in Article 27(3)b has come from small-scale farmers concerned about their access to seeds and being able to continue producing. Many governments in the South have expressed concern that food security could be negatively affected, both among the smallholder farm sector, but also on urban consumers through lower production and higher prices. There has been support though from more productive and modernized segments of the farm sector who can benefit from improved access to technology and international markets. The analysis here suggests that such farmers may also see pecuniary benefits from reducing competing production from farms using copied or imitation seed. Perhaps for similar reasons, farm businesses in the North have also lobbied their own governments to exercise pressure on developing countries to implement TRIPS obligations and increase appropriability. On the other hand, consumer groups and NGOs in developed countries have, if anything, expressed concern about the potential effects on food prices and food security. This analysis remains however essentially static by not considering the effects on the incentive to innovate in the future. Such extensions are discussed below in the concluding section.

3.4 Conclusions

The analysis has elaborated a simple model of innovation in the production of an intermediate product to examine the effects of different levels of appropriability enacted through an IPR system. The model accounts for heterogeneity among producers of the final good, with agricultural production and the use of planting material as the motivating context. Beginning with a single country setting, while a monopolist innovator benefits most from maximum appropriability, the intermediate producers (farms) have differing interests. The more productive among them, or those best placed to profit from an improved variety, will benefit from the greater level of innovation that maximum appropriability would encourage the monopolist to provide. The less productive though, may benefit from a more moderate level of appropriability if this allows a greater number of them access to the seed of the improved variety, possibly even through illicit ("pirated") copies. As the final food product is homogeneous and unaffected by the level of innovation, consumers benefit from maximum production, which implies a moderate level of appropriability. If appropriability were too low, then the resulting decline in the level of innovation and quality of the seed, would have a negative effect on production, as fewer farms would find it profitable to produce.

The results of the analysis here for the level of farm production are similar to what has been obtained in recent literature on the piracy of copyrighted ICT technologies, although in that case, consumers correspond to farms, or the intermediate producers. The addition of the extra level of production introduces an interdependence between intermediate goods producers, and also highlights a novel dimension of the traditional innovation-diffusion tradeoff. The aggregate interest of the farm sector is most closely aligned to that of the monopolist, in preferring maximum appropriability and innovation. But there is a minority of farms that do not benefit and are excluded from producing, and their interests lie closer to those of consumers, who benefit from greater production and lower prices. This can help explain the political alliance between farm groups representing more "marginal" farms and also consumers' associations in general opposition to stronger IPRs for the plant breeding sector. Opposition from consumers to the application of modern biotechnology to breeding in the form of genetically modified varieties is often based on concerns about concentration in the sector, as well as the more conventional suspicions concerning the integrity and the trustworthiness risk assessment policies and procedures. If breeding produces new varieties with primarily agronomic characteristics that are of benefit to farmers, but not directly relevant to consumers, then the latter are less likely to appreciate these.

Clearly the results obtained are based partly on the specific formulations for demand of the final production good, as well as the distribution of farms. An important extension to explore is to take a more general approach to see which propositions can be developed when only general characteristics of the functions are assumed[13]. This is complicated by the interdependence among the farms and is left to further work. It is possible to anticipate though that the result of a fixed proportion of farms purchasing the seed from the monopolist is likely to give way in such a setting to a less determinate result which might reveal more complicated tradeoffs in interests concerning appropriability. For example, it is logical to expect that higher appropriability and a level of innovation would decrease the proportion of farms finding it profitable to purchase the monopolist's seed, whose profits may be maximized by attenuating the corresponding increases in price.

A more fundamental limitation to this framework is its essentially static nature. As has been done by many authors, the decision to invest in quality is interpreted as encompassing the dynamic nature of the issue. One can then also compare appropriability that maximizes innovation versus appropriability that maximizes current welfare, presupposing that long term welfare will depend even more on innovation. The intermediate product case analyzed in the current paper illustrates though that whether consumers surplus would be monotonically increasing in innovation may not necessarily be the case, and an analysis that differentiates between different circumstances might be warranted. More generally, a dynamic model is also an obvious extension, either through multiple decision periods, or beginning with a simple two-period framework. This perspective is quite relevant for the agricultural sector, given the predator-prey relationship characterizing the development of new crop varieties in the face of continually evolving pests (Goeschl and Swanson, 2003). Innovation is necessary simply to maintain current production levels and thus consumer welfare.

To examine some of the issues at stake with the coming into force of the TRIPS Agreement and the requirement that all WTO members provide for IPR protection of agricultural plant varieties, the analysis is extended to a two-country setting. In an autarkic situation, the monopolist, based in the North, begins marketing its seed to farms in the South. But now, as the level of quality is given, diffusion of the monopolist's product in the South, including through less productive copies, is maximized with a minimal level of appropriability, which also benefits consumers more by raising production. In an agricultural context, minimal appropriability also maximizes the number of farms able to produce. Given food security concerns at both household and national level, this can help explain reluctance among Southern governments to accept and implement TRIPS obligations, as well as opposition to such policies by more modernized and productive segments of the farm sector.

In the situation where there is international trade in the farm product, the interests of farms in the North and the South become interdependent, as do those of consumers in both countries. The analysis has shown how farms in the North, both those purchasing seed and those using copied seed would be supportive of a raising of the appropriability level in the South, while farms there would not benefit. Such pressure has been

[13] As done by Bae and Choi (2006).

witnessed, but has had little or no support from consumers in either region which may reflect the fact that this would raise prices for them.

As admitted, all of this two-country analysis takes the level of quality as given. An interesting extension, in the same spirit as a more dynamic formulation, would be to examine the subsequent effect of different levels of appropriability on the monopolist's incentive to invest in innovation. This is relevant to the TRIPS perspective, but it may also be interesting to allow for the emergence and entry of a competing innovator in the South, possibly facing a choice between piracy and its own innovation. Nonetheless, the portrayal of different interests in the current paper may correspond reasonably well to the initial, and to some extent ongoing, debates concerning TRIPS and Article 27(3)b, in which stakeholders are possibly reflecting relatively short term perspectives.

A final note concerns the potential applicability of the analysis here to the context of digital products subject to copyright protection, such as software or entertainment media, which motivated the models upon which the present paper builds. The analysis of Bae and Choi (2006) and Belleflamme and Picard (2007) considers products that are typically final consumption goods, such as digital music or video. Many of the most widely used software products though, such as operating systems and office applications, are used as much if not more by businesses and may also be considered as intermediate goods. Thus, further pursuing this line of analysis may be of broader relevance.

3.5 Annex

3.5.1 Proof of Proposition 2

Total profits of farms purchasing from the monopolist are maximized with maximum appropriability.

Profits for farmers purchasing the monopolist's seed are calculated by integrating the expression for profits at θ over the interval $(\theta_1, \bar{\theta})$, recalling that $\theta_1 = \bar{\theta}/2$:

$$\begin{aligned}
\tau_1 &= \int_{\theta_1}^{\bar{\theta}} (g\theta u - p_1)\,\mathrm{d}\theta \\
&= \int_{\theta_1}^{\bar{\theta}} \left(\left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{4\bar{\theta}Sr(1-\delta)} \cdot \theta \right] - \frac{\delta c}{2(1-\delta)} - \frac{\delta^2 b^2 \bar{\theta}}{8Sr} - c \right) \mathrm{d}\theta \\
&= \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{8\bar{\theta}Sr(1-\delta)} \right] \left(\bar{\theta}^2 - \theta_1^2\right) \\
&\quad - \left[\frac{\delta c}{2(1-\delta)} + \frac{\delta^2 b^2 \bar{\theta}}{8Sr} + c \right] \left(\bar{\theta} - \theta_1\right) \\
&= \frac{3b^2\delta\bar{\theta}^2 - 2b^2\delta^2\bar{\theta}^2}{32Sr} + \frac{3\bar{\theta}c - 2\delta\bar{\theta}c}{8(1-\delta)} - \frac{\bar{\theta}c}{2} \\
&= \frac{\delta(3-2\delta)b^2\bar{\theta}^2}{32Sr} + \frac{\bar{\theta}c(3-2\delta)}{8(1-\delta)} - \frac{\bar{\theta}c}{2}\,. \qquad (3.15)
\end{aligned}$$

The effect of different levels of appropriability on farm profits is examined by differentiating τ_1 with respect to δ:

$$\frac{\mathrm{d}\tau_1}{\mathrm{d}\delta} = \frac{(3-4\delta)b^2\bar{\theta}^2}{32Sr} + \frac{\bar{\theta}c}{8(1-\delta)^2}$$

This expression is positive for $0 < \delta < 3/4$, meaning that farm profits are increasing in appropriability at least until that level. A local maximum or minimum would imply that

$$(1-\delta)^2(4\delta-3) = \frac{4Scr}{\bar{\theta}b^2}$$

and interest centers on situations where this expression > 0, which implies that

$$\begin{aligned}
4\delta^3 - 11\delta^2 - 2\delta - 3 &> 0 \\
\Rightarrow 4\delta^3 - 11\delta^2 - 2\delta &> 0 \\
\Rightarrow \delta(4\delta^2 - 11\delta - 2) &> 0
\end{aligned}$$

for $3/4 < \delta < 1$. The quadratic expression $4\delta^2 - 11\delta - 2$ has the roots $\delta = (11 \pm \sqrt{153})/8 = -0.17$ and 2.92 and a minimum at $\delta = 11/8$. Therefore $\delta(4\delta^2 - 11\delta - 2) < 0$ over the interval $3/4 < \delta < 1$, and τ_1 is increasing in δ over this interval (with $\lim_{\delta \to 1} \tau_1 \to \infty$) . □

3.5.2 Proof of Proposition 3

Profits for farms using copied seed could be maximized at the moderate level of appropriability $\delta = 1/2$ provided the strength of demand for the farm's product sufficiently exceeds the cost of producing seed.

The expression for profits of farms producing copied seed can be derived integrating the appropriate expression for over the interval (θ_c, θ_1):

$$\begin{aligned}
\tau_c &= \int_{\theta_c}^{\theta_1} [g(1-\delta)\theta u - c] \, \mathrm{d}\theta \\
&= \int_{\theta_c}^{\theta_1} \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{4\bar{\theta}Sr} \cdot \theta - c \right] \mathrm{d}\theta \\
&= \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{8\bar{\theta}Sr} \right] \left[\frac{\bar{\theta}^2}{4} - \frac{16\bar{\theta}^2 S^2 c^2 r^2}{[\bar{\theta}\delta(1-\delta)b^2 + 4Scr]^2} \right] \\
&\quad -c \left[\frac{\bar{\theta}}{2} - \frac{4\bar{\theta}Sc^2 r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} \right] \\
&= \frac{\bar{\theta}^2\delta(1-\delta)b^2 + 4\bar{\theta}Scr}{32Sr} + \frac{2\bar{\theta}Sc^2 r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{\bar{\theta}c}{2} \\
&= \frac{\bar{\theta}^2\delta(1-\delta)b^2}{32Sr} + \frac{2\bar{\theta}Sc^2 r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{3}{8}\bar{\theta}c
\end{aligned} \tag{3.16}$$

As this is quite nonlinear in δ, we maximize profit with respect to appropriability:

$$\frac{\mathrm{d}\tau_c}{\mathrm{d}\delta} = \frac{(1-2\delta)b^2\bar{\theta}^2}{32Sr} - \frac{2\bar{\theta}^2 Sc^2 r b^2 (1-2\delta)}{[\bar{\theta}\delta(1-\delta)b^2 + 4Scr]^2};$$

and clearly $\delta = {}^1/_2$ is one solution to ${}^{\mathrm{d}\tau_c}/_{\mathrm{d}\delta} = 0$. Other solutions are found by looking for other roots to this equation,

$$\begin{aligned}
\frac{\mathrm{d}\tau_c}{\mathrm{d}\delta} = 0 \Rightarrow & \quad \tfrac{(1-2\delta)b^2\bar{\theta}^2}{(1-2\delta)b^2\bar{\theta}^2} = \tfrac{64S^2c^2r^2}{[\bar{\theta}\delta(1-\delta)b^2+4Scr]^2} \\
\Rightarrow & \quad \bar{\theta}^2\delta^2(1-\delta)^2b^4 + 8Scr\bar{\theta}\delta(1-\delta)b^2 - 48S^2c^2r^2 = 0 \\
\Rightarrow & \quad \left[\bar{\theta}\delta(1-\delta)b^2 + 12Scr\right]\left[\bar{\theta}\delta(1-\delta)b^2 - 4Scr\right] = 0 \\
\Rightarrow & \quad \bar{\theta}\delta(1-\delta)b^2 = 4Scr
\end{aligned}$$

since the other root would imply that δ is not in $(0,1)$. Solving this using the formula for quadratic roots yields,

$$\begin{aligned}
\delta &= \frac{\bar{\theta}b^2 \pm \sqrt{\bar{\theta}^2b^4 - 16\bar{\theta}b^2Scr}}{2\bar{\theta}b^2} \\
&= \frac{1}{2} \pm \sqrt{\frac{1}{4} - \frac{4Scr}{\bar{\theta}b^2}}. \qquad (3.17)
\end{aligned}$$

Both roots will be in $(0,1)$, provided that

$$\frac{4Scr}{\bar{\theta}b^2} < \frac{1}{4}, \qquad (3.18)$$

since an equality leads to the known root $\delta = {}^1/_2$. Although the model is not defined at $\delta = 0$ or $\delta = 1$, evaluating ${}^{\mathrm{d}\tau_c}/_{\mathrm{d}\delta}$ at these values indicates that the derivative is negative at values of δ just exceeding 0 and is positive at values approaching 1. Therefore given (3.18), there can be one local maximum at $\delta = {}^1/_2$ for ${}^{\mathrm{d}\tau_c}/_{\mathrm{d}\delta}$ and two local minima in the interval $\delta \in (0,1)$, with the minima defined by (3.17). By noting that $\tau_c = {}^{\bar{\theta}c}/_8$ for $\delta = 0$ or $\delta = 1$, total profits for all farms purchasing copied seed (τ_c) are essentially the same with either minimum or maximum appropriability, although with minimum appropriability these profits are divided over a much larger group (θ_c will be lower). If the local maximum for total profits exceeds the value at minimum and maximum appropriability, then

$$\frac{\bar{\theta}^2\delta(1-\delta)b^2}{32Sr} + \frac{2\bar{\theta}Sc^2r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{3\bar{\theta}c}{8} > \frac{\bar{\theta}c}{8}.$$

Evaluating at $\delta = {}^1/_2$ implies

$$\frac{\bar{\theta}b^2}{128Sr} + \frac{8Sc^2r}{\bar{\theta}b^2 + 16Scr} > \frac{c}{2} \text{ or}$$

$$
\begin{aligned}
\frac{8Sc^2r}{\bar{\theta}b^2 + 16Scr} &> \frac{64Scr - \bar{\theta}b^2}{128Sr} \\
1024S^2c^2r^2 &> \left[64Scr - \bar{\theta}b^2\right]\left[\bar{\theta}b^2 + 16Scr\right] \\
1024S^2c^2r^2 &> 1024S^2c^2r^2 + 48Scr\bar{\theta}b^2 - \bar{\theta}^2b^4 \\
\Rightarrow \bar{\theta}b^2 &> 48Scr \text{ which can be rearranged as} \\
\frac{4Scr}{\bar{\theta}b^2} &< \frac{1}{12}\,. \square
\end{aligned}
\tag{3.19}
$$

This sets a stricter limit than in (3.18) and can be interpreted as follows: if the strength of demand for the final product is sufficiently larger, in relative terms, than the cost of producing and copying seed, then total profits for farms using copied seed will be maximized with "moderate" appropriability, defined as $\delta = 1/2$. The range of values for δ for which total profits exceed those at minimum or maximum appropriability rises as the ratio between final demand and cost of the input increases.

3.5.3 Proof of Proposition 4

Consumers benefit most from a moderate level of appropriability, set at $\delta = 1/2$.

Substituting (3.6) into (3.1),

$$
g = \frac{b}{S\bar{\theta}} + \frac{4cr}{\delta(1-\delta)b\bar{\theta}^2}\,.
$$

Differentiating,

$$
\frac{\mathrm{d}g}{\mathrm{d}\delta} = \frac{4cr(2\delta - 1)}{b\bar{\theta}^2\delta^2(1-\delta)^2}
$$

and setting to 0 implies that $\delta = 1/2$. The second derivative is

$$
\begin{aligned}
\frac{\mathrm{d}^2g}{\mathrm{d}\delta^2} &= \frac{4cr}{b\bar{\theta}^2}\left[\frac{2\delta^2(1-\delta)^2 - (2\delta-1)(2\delta - 6\delta^2 + 4\delta^3)}{\delta^4(1-\delta)^4}\right] \\
&= \frac{8cr}{b\bar{\theta}^2}\left[\frac{\delta^2(1-\delta)^2 + \delta(1-2\delta)^2(1-\delta)}{\delta^4(1-\delta)^4}\right] \\
&= \frac{8cr}{b\bar{\theta}^2}\left[\frac{\delta(1-\delta) + (1-2\delta)^2}{\delta^3(1-\delta)^3}\right]\,.
\end{aligned}
$$

Whether this is positive or negative at $\delta = 1/2$ depends on

$$
\begin{aligned}
&\delta^2(1-\delta)^2 + \delta(1-2\delta)^2(1-\delta) \\
&= -3\delta^3 + 6\delta^2 - 4\delta + 1 \\
&= 0.125 > 0, \text{ evaluated at } \delta = 1/2\,.
\end{aligned}
$$

Therefore the consumer price g of the farm product is minimized at $\delta = {}^1/_2$.. □

3.5.4 Proof of Proposition 6

Total profits of farms in the South purchasing the monopolist's seed are maximized with a maximum level of appropriability that is feasible.

Profits for farms purchasing the monopolist's seed are determined, as above, by

$$\begin{aligned}
\tau_{1S} &= \int_{\theta_{1S}}^{\bar{\theta}_S} (g_S u\theta - p_{1S})\mathrm{d}\theta \\
&= \int_{\theta_{1S}}^{\bar{\theta}_S} \left[\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\cdot\theta - p_{1S}\right]\mathrm{d}\theta \\
&= \left[\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\cdot\frac{\theta^2}{2} - p_{1S}\theta\right]_{\theta_{1S}}^{\bar{\theta}_S} \\
&= \left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\left(\frac{\bar{\theta}_S^2}{2} - \frac{\bar{\theta}_S^2}{8}\right) - p_{1S}\frac{\bar{\theta}_S}{2} \\
&= \frac{3\bar{\theta}_S}{8}\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S}{2}\left(\frac{\delta_S[b_S(1-\delta_S)u + S_S c]}{2S_S(1-\delta_S)} + c\right) \\
&= \frac{3\bar{\theta}_S}{8}\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\delta_S\bar{\theta}_S}{4}\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S c}{2} \\
&= \frac{\bar{\theta}_S}{8}(3-2\delta_S)\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S c}{2} \\
&= \frac{\bar{\theta}_S}{8}(3-2\delta_S)\left(\frac{b_S u}{S_S} + \frac{c}{1-\delta_S}\right) - \frac{\bar{\theta}_S c}{2}\ .
\end{aligned}$$

Maximizing with respect to δ_S,

$$\begin{aligned}
\frac{\partial\tau_{1S}}{\partial\delta_S} &= \frac{\bar{\theta}_S}{8}\left(\frac{3c}{(1-\delta_S)^2} - \frac{2b_S u}{S_S} - \frac{2c(1-\delta_S) + 2\delta_S c}{(1-\delta_S)^2}\right) \\
&= \frac{\partial\tau_{1S}}{\partial\delta_S}\frac{\bar{\theta}_S}{8}\left(\frac{c}{(1-\delta_S)^2} - \frac{2b_S u}{S_S}\right),\ \text{and } = 0 \Rightarrow \\
(1-\delta_S)^2 &= \frac{S_S c}{2b_S u}\ \text{ or }\ \delta_S = 1 \pm \sqrt{\frac{S_S c}{2b_S u}}\ . \qquad (3.20)
\end{aligned}$$

Since ${}^{\partial^2\tau_{1S}}/_{\partial\delta^2} = \bar{\theta}_S c/4(1-\delta_S)^3 > 0$, then the solution is a minimum. A minimum point will be found in $(0,1)$ if $S_S c < b_S u$ (and the negative root is taken). It is also clear that τ_{1S} approaches $\frac{\bar{\theta}_S}{8}\left(\frac{3b_S u}{S_S}+3c\right)-\frac{\bar{\theta}_S c}{2}$ as δ_S approaches 0, but tends to ∞ as δ_S approaches 1. Therefore, while a minimum might be found in the range $(0,1)$, the maximum will always be as $\delta_S \to 1$. □

3.5.5 Proof of Proposition 7

Under autarky, total profits for farms in the South using copied seed will be maximized with a minimal level of appropriability if the strength of demand sufficiently exceeds the cost of producing seed.

Profits for farms using copied seed are

$$\begin{aligned}
\tau_{cS} &= \int_{\theta_{cS}}^{\theta_{1S}} [g_S(1-\delta_S)u\theta - c]\,\mathrm{d}\theta \\
&= \left[\frac{b_S(1-\delta_S)u}{S_S\bar{\theta}_S}+\frac{c}{\bar{\theta}}\right]\left[\frac{\theta_{1S}^2}{2}-\frac{\theta_{cS}^2}{2}\right]-c(\theta_{1S}-\theta_{cS}) \\
&= \frac{b_S(1-\delta_S)u+S_Sc}{S_S\bar{\theta}_S}\left[\frac{\bar{\theta}_S^2}{8}-\frac{S_S^2\bar{\theta}^2c^2}{2[b_S(1-\delta_S)u+S_Sc]^2}\right]-c\left[\frac{\bar{\theta}_S}{2}-\frac{S_S\bar{\theta}_Sc}{[b_S(1-\delta_S)u+S_Sc]}\right] \\
&= \frac{\bar{\theta}_S[b_S(1-\delta_S)u+S_Sc]}{8S_S}+\frac{S_S\bar{\theta}_Sc^2}{2[b_S(1-\delta_S)u+S_Sc]}-\frac{\bar{\theta}_Sc}{2}\,. \qquad (3.21)
\end{aligned}$$

The first term is increasing in δ_S and the second term, decreasing, which implies counteracting effects of appropriability on total farm profits. Maximizing profits with respect to δ_S leads to the following:

$$\frac{\partial\tau_{cS}}{\partial\delta_S}=-\frac{\bar{\theta}_Sb_Su}{8S_S}+\frac{S_S\bar{\theta}_Sc^2b_Su}{2[b_S(1-\delta_S)u+S_Sc]^2} \text{ and } \frac{\partial\tau_{cS}}{\partial\delta_S}=0 \;\Rightarrow$$

$$\begin{aligned}
[b_S(1-\delta_S)u+S_Sc]^2 &= 4S_S^2c^2 \\
b(1-\delta_S) &= S_Sc \\
\delta_S &= 1-\frac{S_Sc}{b_Su} \qquad (3.22)
\end{aligned}$$

which will be in the interval $(0,1)$ if $S_Sc < b_Su$. Since

$$\frac{\partial^2\tau_{cS}}{\partial\delta_S^2}=\frac{S_S\bar{\theta}_Sc^2b_S^2u^2}{[b_S(1-\delta_S)u+S_Sc]^3}>0\,,$$

the critical point for δ_S is minimum, implying that total profits will be maximized at either the minimum or maximum level of appropriability. As $\delta_S \to 1$,

$$\frac{\partial \tau_{cS}}{\partial \delta_S} \to -\frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta} c^2 b_S u}{2S_S^2 c^2} = \frac{3\bar{\theta}_S b_S u}{8S_S} > 0$$

and so the maximum value for τ_{cS} could be at this end of the interval $(0, 1)$; it would be at the other lower end of the interval if $S_S c < b_S u$ by a sufficient amount. To determine this, note that total profits for farms using copied seed, from 3.21, can be written

$$\tau_{cS} = \frac{\bar{\theta}_S b_S (1-\delta_S) u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2[b_S(1-\delta_S) + S_S c]} - \frac{3\bar{\theta}_S c}{8} .$$

As $\delta_S \to 0$,

$$\tau_{cS} \to \frac{S_S \bar{\theta}_S c^2}{2S_S c} - \frac{3\bar{\theta}_S c}{8} = \frac{\bar{\theta}_S c}{8}$$

and as $\delta_S \to 1$,

$$\tau_{cS} \to \frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2(b_S u + S_S c)} - \frac{3\bar{\theta}_S c}{8} .$$

So for the value of τ_{cS} to be greater as $\delta_S \to 0$, than as $\delta_S \to 1$, then

$$\begin{aligned}
\frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2(b_S u + S_S c)} - \frac{\bar{\theta}_S c}{2} &> 0 \\
\frac{b_S u(b_S u + S_S c) + 4S_S^2 c^2 - 4S_S c(b_S u + S_S c)}{8S_S(b_S u + S_S c)} &> 0 \\
b_S u(b_S u - 3S_S c) &> 0 \\
\Rightarrow \; S_S c &< \frac{b_S u}{3} .
\end{aligned} \tag{3.23}$$

Thus, if $S_S c < b_S u$, then the value of δ_S which minimizes total farm profits (using copied seed) is between 0 and 1. If $b_S u/3 < \delta_S < b_S u$, then profits will be maximized at the maximal level of appropriability (as $\delta_S \to 1$). If $S_S c < b_S u/3$, then profits will be maximized at the lowest level of appropriability (as $\delta_S \to 0$). □

3.5.6 Proof of Proposition 10

Given weaker final product demand and/or a larger mass of farms in the South, opening to trade in the final product market will lead to lower overall profits for farms in the North producing with copied seed, and higher overall profits for such farms in *the South, provided that the strength of demand in each market is sufficiently strong relative to the cost of producing seed.*

As in sec. 3.5.2, profits for farms using copied seed in country i (see (3.16)) can be written as

$$\begin{aligned}
\tau_{ci} &= \int_{\theta_{ci}}^{\theta_{1i}} [g_i(1-\delta_i)u\theta - c]\,\mathrm{d}\theta \\
&= \frac{g_i(1-\delta_i)u}{2}\left(\theta_{1i}^2 - \theta_{ci}^2\right) - c\left(\theta_{1i} - \theta_{ci}\right) \\
&= \frac{g_i(1-\delta_i)u}{2}\left(\frac{\bar{\theta}_i^2}{4} - \frac{c^2}{g_i^2(1-\delta_i)^2u^2}\right) - c\left(\frac{\bar{\theta}_i}{2} - \frac{c}{g_i(1-\delta_i)u}\right) \\
&= \frac{g_i(1-\delta_i)u\bar{\theta}_i^2}{8} + \frac{c^2}{2g_i(1-\delta_i)u} - \frac{c\bar{\theta}_i}{2}\,. \qquad (3.24)
\end{aligned}$$

The relationship to g_i is unclear in this expression, but differentiating profits leads to

$$\frac{\partial \tau_{ci}}{\partial g_i} = \frac{(1-\delta_i)u\bar{\theta}_i^2}{8} - \frac{c^2}{2g_i^2(1-\delta_i)u}\,; \qquad (3.25)$$

For this derivative to be positive,

$$\begin{aligned}
2g_i^2(1-\delta_i)^2u^2\bar{\theta}_i^2 &> 8c^2 \text{ or} \\
g_i^2(1-\delta_i)^2u^2\bar{\theta}_i^2 &> 4c^2\,. \qquad (3.26)
\end{aligned}$$

Substituting for

$$g_i u = \frac{b_i u}{S_i\bar{\theta}_i} + \frac{c}{\bar{\theta}_i(1-\delta_i)}$$

leads to

$$\begin{aligned}
(1-\delta_i)^2\bar{\theta}_i^2\left(\frac{b_i u}{S_i\bar{\theta}_i} + \frac{c}{\bar{\theta}_i(1-\delta_i)}\right)^2 &> 4c^2 \\
\Rightarrow \frac{b_i(1-\delta_i)}{S_i} &> 2c \\
\frac{b_i(1-\delta_i)}{S_i} &> c \qquad (3.27)
\end{aligned}$$

Therefore, if the strength of demand sufficiently exceeds the cost of producing seed, then the profits of farms using copied seed increase in final product demand. So if trade leads to a world price, g_W, lower than the price in the North under autarky, g_N, then farms using copied seed in the North lose from trade, and conversely for farms in the South using copied seed.

4 Trade and intellectual property rights in the agricultural seed sector

4.1 Introduction

This chapter analyses the effect of intellectual property rights (IPRs) on trade in goods.[1] IPRs enterred the trade agenda with the negotiation of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) as part of the Uruguay Round leading to the creation of the World Trade Organization (WTO). Northern countries, led by the US and the EU, have argued that developing countries and economies in transition will benefit from introducing IPR systems, such as patents, trademarks and copyright, from a stimulating effect on technology transfer through trade, licensing and foreign direct investment. On the other side, Southern countries have voiced concerns about the potential negative effects for domestic industries and the exercise of monopoly power by Western-based multinational companies. Our analysis concentrates on the effects on trade as a channel for technology transfer.

From a theoretical point of view, the extent to which the introduction and/or strengthening of IPRs encourages trade has been examined in the theoretical literature with mixed results. Grossman and Lai (2004), building on Grossman and Helpman (1990) and Lai and Qiu (2003), have analysed the general equilibrium effects of IPRs. Considering static effects, stronger IPRs in a country with weaker innovative capacity could encourage trade as exporters of products vulnerable to being copied (located in a country with greater R&D capacity) benefit from a market expansion effect (Taylor, 1994). On the other hand, it has been suggested that stronger IPRs might improve the ability of exporters to exercise monopoly power in smaller and less competitive markets, resulting in higher prices and lower quantities (Maskus and Penubarti, 1995). A second reason for a decline in trade is that stronger IPRs will encourage exporting companies to change their mode of serving the foreign market from exports to some form of foreign direct investment (FDI) or licensing of protected products, and may also encourage the development of domestic innovative capacity that would eventually displace imports (Helpman, 1993). These latter effects incorporate dynamic

[1] Useful comments and suggestions on earlier versions have been received from Erwin Bulte, Timo Goeschl, Marijke Kuiper, Alfons Oude Lansink, Niels Louwaars, Peter Phillips, Stuart Smyth, Arthur van Soest, Tim Swanson and Frank van Tongeren, as well as numerous participants at the 2008 EAAE Congress in Ghent, Belgium, and the 2009 Conference of the Canadian Association of Agricultural Economists in Toronto, Canada. The expert assistance of Henk Kelholt in the extraction and organization of the seed trade data is gratefully acknowledged.

considerations, including the effect of IPRs on innovation and its location. Given this theoretical ambiguity, the question is ultimately an empirical one.

Quantitative empirical studies of the effect of IPRs on trade have typically been undertaken at a fairly aggregated level involving trade in all goods and services, possibly disaggregated according to broad industry levels. Such studies have generally suggested that stronger IPRs may stimulate international trade in some specific sectors, while not in others (see Fink and Primo Braga, 2005; Maskus and Penubarti, 1995). Smith (1999) found that US exports were positively correlated with stronger IPRs in importing countries that pose an imitation threat but negatively correlated in other countries. In a subsequent analysis at a more specific sectoral level, Smith (2002) produced similar results for US pharmaceutical exports.

One sector of particular interest in terms of WTO TRIPS negotiations concerns the agricultural plant breeding and seed sector. As explained in chapter 1, Article 27.3(b) of the TRIPS Agreement requires WTO member countries to offer some form of intellectual property protection for new plant varieties, either in the form of patents (common in the U.S.) or plant breeder's rights (PBR) which were first developed in Europe. PBRs[2] are a *sui generis* form of IPR that can be seen as combining elements of both patents and copyright protection and which were perceived as addressing some of the peculiar aspects of protecting biologically-reproducible material, such as plants, in a better manner than patents. PBRs have existed in many European countries for more than 40 years and the general requirements for such protection are enshrined in the International Convention on the Protection of New Varieties of Plants (UPOV Convention).

This chapter assesses the effect of UPOV membership, as an indicator of the scope and strength of IPRs affecting the plant breeding sector, on exports of agricultural crop seeds from 10 European countries as well as the US to almost 70 countries around the world. The UPOV Convention has been revised on numerous occasions, and our analysis distinguishes between the two most recent versions, 1978 and 1991, which are relevant today. The 1991 version offers the holder of a PBR more exclusive rights than the 1978 version, primarily by restricting the saving of seed by farmers, even for own use, unless an explicit exemption is legislated. Although countries may no longer join UPOV with adhesion to the 1978 Treaty, there is no binding requirement that members who had previously done so 'upgrade' to the 1991 version.[3]

In contrast to the ambiguous result in the theoretical literature reviewed above, it can be argued for the specific case of agricultural seeds that the introduction or strengthening of IPRs in countries with generally less innovative capacity in plant breeding will lead to an increase in seed imports from those countries possessing such capacity. The ease of reproducing (low cost of imitating) agricultural seed implies that there is little incentive to export to markets where these cannot be adequately protected. The difference with other goods that are easily imitated, such as software or pharmaceutical drugs, is that an imitator needs to acquire a sufficient quantity, in

[2]This form of protection is also referred to as plant variety protection (PVP); see chapter 1.

[3]WTO members may actually elect to implement PBR conformant to UPOV 1978, without becoming a UPOV member, and still be meeting their TRIPS obligations.

physical terms, of the seed. Such goods can be more easily imitated even if they have not been marketed in a country. This also means that the monopoly power effect is not expected to play much of a role in the agricultural seed market. Exporting firms would most likely expand their range of seed products exported to a country introducing IPRs. These would most likely be newer and more valuable varieties with higher prices. Some farmers in the importing country would choose to purchase the newer seed, while some may still continue purchasing any previously marketed, lower-value imported varieties. Thus, there is little reason to expect that the flow of imports would not increase in value terms in the short term, with the important provision that the IPRs introduced actually offer effective protection. In the longer term, the effects on location of innovation and production could though influence flows.

The effects of stronger IPRs on seed trade has recently been analysed by Yang and Woo (2006), who examined US seed exports to 60 importing countries over the period 1990-2000. US seed exports generally increased over this period and in a static linear panel formulation of the gravity model, Yang and Woo observed a positive significant effect for importing country membership in UPOV. This effect however essentially disappeared in a dynamic formulation (including a one-period lag of seed imports), leading the authors to argue that American seed exports exhibit a certain degree of state dependence, and that there was no significant correlation with IPRs.

The current chapter builds on and extends the analysis of Yang and Woo. First, in addition to US exports, which account for about one-fifth of exports in the world, we also compile data on exports from 10 European countries, comprising the largest seed producers and exporters in that region. Thus, the two major seed exporting economies in the world are included in the analysis. This is partly motivated by the observation that PBR systems in Europe are generally stronger than in the US, a difference that might be reflected more in considerations taken by European based seed companies. Furthermore, European exports tend to be for different crops and the pattern of importers is also different compared to the US. Second, the dataset covers a longer period (1989-2007) for many importers. Note that a period of 15-20 years corresponds to the approximate amount of time necessay to develop and commercialize new plant varieties (e.g. Tripp, Eaton and Louwaars, 2006). Thus, over this period, it can be expected that static effects of IPRs (increasing trade flows) should dominate and that long-term or dynamic effects will not yet be detectable. Finally, the current analysis also extends that of Yang and Woo by differentiating between the 1978 and 1991 versions of the UPOV Treaty.

Our results do not find any evidence that adoption of UPOV-approved system of PBR positively influences the seed imports, confirming the results of Yang and Woo. This seems fairly clear in the raw data but we apply recently-developed quantile regression techniques to panel data to investigate the issue more systematically. Quantile regression offers the advantage of being robust to outlying observations, as well as capturing possibly different effects of regressors throughout the distribution of the dependent variable, in this case seed imports.

The chapter proceeds below as follows. The second section presents data on seed imports compiled for this study. The third section reviews modeling considerations for econometric modeling of this data and proposes the use of the penalized fixed effects quantile regression. The fourth section discusses the additional data employed and the fifth section presents results of the estimation procedure. The final section concludes and offers some direction for further research.

4.2 Imports of agricultural seed

The full dataset compiled for this study consists of imports of seeds by 79 countries over the period 1989-2007, comprising a wide range of countries of various regions of the world: EU (16), other European (4), North Africa (4), Middle East (4), Sub-Saharan Africa (18), Asia (13), Oceania (2), South and Central America (16) and North America (3).[4] The composition of this list is determined primarily by the availability of the trade statistics, as well as some of the explanatory variables included below. Exports are from the US and 10 principal European exporters: Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, the UK.[5] The export data for these 10 European countries are aggregated together given the research question at hand which concerns primarily the effects of UPOV membership on seed trade flows to countries that have not historically had PBR systems. Furthermore this range of EC countries involved in exporting seed, dominated by the Netherlands and France, masks the fact that most seed production and exporting is undertaken by a relatively limited number of multinational companies of various sizes, often operating with wholly-owned subsidiaries in other countries, acquired during the past few decades reflecting a trend on increasing horizontal concentration.[6] Although official statistics of seed sector sales are not available, it has been estimated by industry sources that the top 9 companies worldwide (including subsidiaries) account for more than 80% of the global commercial seed market (Louwaars et al., 2009). Thus, it seems plausible that decisions concerning exports in this sector from European countries are based more on factors influencing individual company considerations than those that are inherent to specific European countries.[7]

Data on seed exports from the 10 European countries was extracted from the Eurostat trade database[8] and for the United States, from the US Agricultural Trade Database

[4]The list of 79 importing countries is also somewhat larger than the 60 used by Yang and Woo (2006), but the principal results reported below are based on a subsample of 56 importing countries due to limited availability of data for some explanatory variables. Checks for robustness of the results are though undertaken with the full sample.

[5]These exporters are also included as importing countries. Note that Japan is one possible country with considerable exports for which we do not have data.

[6]To illustrate, many seed companies listed on the SeedQuest website (`http://www.seedquest.com`) are owned by larger European companies. For example, L. Daehnfeldt of Denmark is owned by Syngenta; Clause Vegetable Seeds of Spain is a member of the Limagrain Groupe of France; Nunhems in the Netherlands is owned by Bayer Crop Science of Germany.

[7]We undertake some additional robustness analysis to confirm that our principal results do not differ when European exports are disaggregated by country.

[8]Using the Trade Statistics Analysis software developed by LEI, Wageningen UR. The assistance of Henk Kelholt is gratefully acknowledged.

of the USDA's Foreign Agricultural Service.[9] The latter includes a grouping for agricultural seeds, but in the Eurostat database there is no single product classification grouping for seed and planting material; instead there are extended HS8 codes (8 digit Harmonized System codes for traded products) under each product grouping, such as maize or vegetables. In total, there were 64 separate seed product codes at HS8 level. The value of seed exports was converted to constant US dollars with base year 2000.

In general, EU exports considerably outweigh US exports; for example EU exports totalled more than US$ 1,978 million in 2007 against US exports of US$ 765 million (both figures in constant 2000 dollars). A considerable portion of the exports from European countries are destined for each other's markets (almost two-thirds in 1997). EU exports to other countries are US$ 681 million in 2007, which is quite comparable to those of the US to the same countries, at US$ 621 million (constant 2000 dollars). There are however geographic and crop differences which will be discussed below further. EU exports to other EU exporting countries are still considered here as international trade flows in the current study, primarily because of the different points in time at which PBR systems were introduced or revised in Europe.[10]

The value of seed imports for each of the countries from both the US and the EU is presented in Figure 4.1 through Figure 4.6, which are grouped roughly according to region, but with some exceptions to try to include countries with imports of roughly comparable size of imports. The figures also indicate the year that the importing country became a signatory to either the 1978 Act or the 1991 Act of the UPOV treaty.[11] In cases, such as Belgium, where a country acceded to the 1978 Act prior to 1988 and 'upgraded' to the 1991 Act, this is indicated in the figure with an asterix (*) as 'UPOV91*'. And in cases, such as Switzerland or New Zealand where the country, as signatory to the 1978 Act, did not upgrade, 'UPOV78' is presented horizontally (that is, without a specific year) in the figure panel.

The figures illustrate that seed imports vary considerably by country, both between countries and over time, also with substantial fluctuations from year to year. Some show a general increasing trend, while others appear to be mean-reverting. There are also clear differences between EU and US exports. While EU countries import seeds primarily from other EU countries, Canada and Mexico import primarily from the United States, reflecting both similarities in cropping systems, and the general economic integration of the North American Free Trade Association (Figure 4.1). It can also be seen though that Latin American countries in general import considerably more seeds from the US than the EU (Figure 4.4, but with Argentina in Figure 4.1), with the exception of Brazil where imports from the two sources are of comparable value.

[9] http://www.fas.usda.gov/ustrade/USTHome.asp?QI=

[10] And we also differentiate among US exports to each of these 10 EU exporters.

[11] The data is taken from the UPOV website (www.upov.org) and various official meeting documents available there. Note also that a number of EU countries are indicated as acceding to the 1991 Act of UPOV in 1995, when in fact the accession process may have taken longer. Such countries were however members of the EC's Community Plant Variety Organization (CPVO) which in 1995 implemented a membership-wide PBR that was conform to the 1991 Act.

In terms of PBRs, there is also a wide range of situations. EU countries were among the first to move to UPOV 1991 from the 1978 version. Other industrialized countries, such as the US or Japan took longer (respectively 1999 and 1998), while notably neither Canada nor New Zealand had signed the 1991 Act as of 2004. Seed imports in Australia and New Zealand are considerably lower than many other industrialized countries. One might be tempted to infer that Australia's adoption of UPOV 1978 Act in 1989 preceded a steady increase in seed imports through the 1990s, but this trend did not change with the adoption of the 1991 Act in 2000. New Zealand's imports of seed are relatively minimal, despite the adoption of the 1978 Act earlier in the 1980s, perhaps reflecting partly the lesser importance of crop production in its agricultural sector.

Looking at a variety of European countries, including new EU members (Figure 4.2), essentially all are members of UPOV. But whereas some Central and Eastern European countries such as Bulgaria, Romania and Hungary have now acceded to the 1991 Act, other fairly high-income countries such as Norway and Switzerland have remained with the 1978 Act.[12] It might be inferred from the graph that Bulgaria's joining UPOV 1991 led to an increase in seed imports in subsequent years. Such a hypothesis might also hold for Romania but the earlier fluctuations in seed imports to this country suggest the importance of some other factors.

Considering the experiences of Latin American countries (Figure 4.4), it is clear that none of these had adopted the 1991 Act (as of 2004). Indeed, there are almost no examples of developing countries joining UPOV 1991 within (or before) the sample period (exceptions include Jordan, Tunisia and Singapore). For countries such as Argentina (actually shown in Figure 4.1), Brazil, Colombia and Chile, it seems that UPOV 1978 membership came after an earlier surge in seed imports. Perhaps for Argentina, this was followed by a further acceleration in seed imports, which then perhaps for reasons related to the economic crisis beginning in the late 1990s, decreased markedly. Other countries, such as Costa Rica, Guatemala, and Peru have had a general rising trend in seed imports without any PBR protection.

[12] These countries are not members of the European Community Plant Variety Protection Office (CPVO) which would require them to respect the terms of the 1991 Act.

Figure 4.1: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 1 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

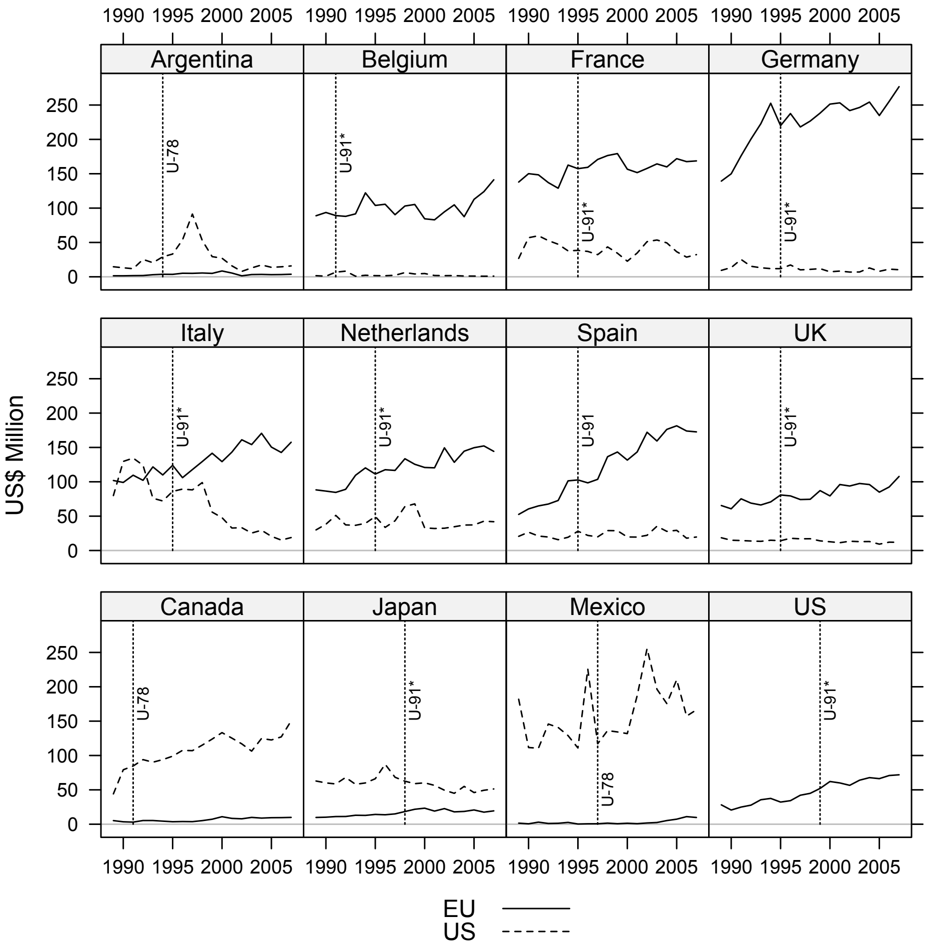


Figure 4.2: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 2 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

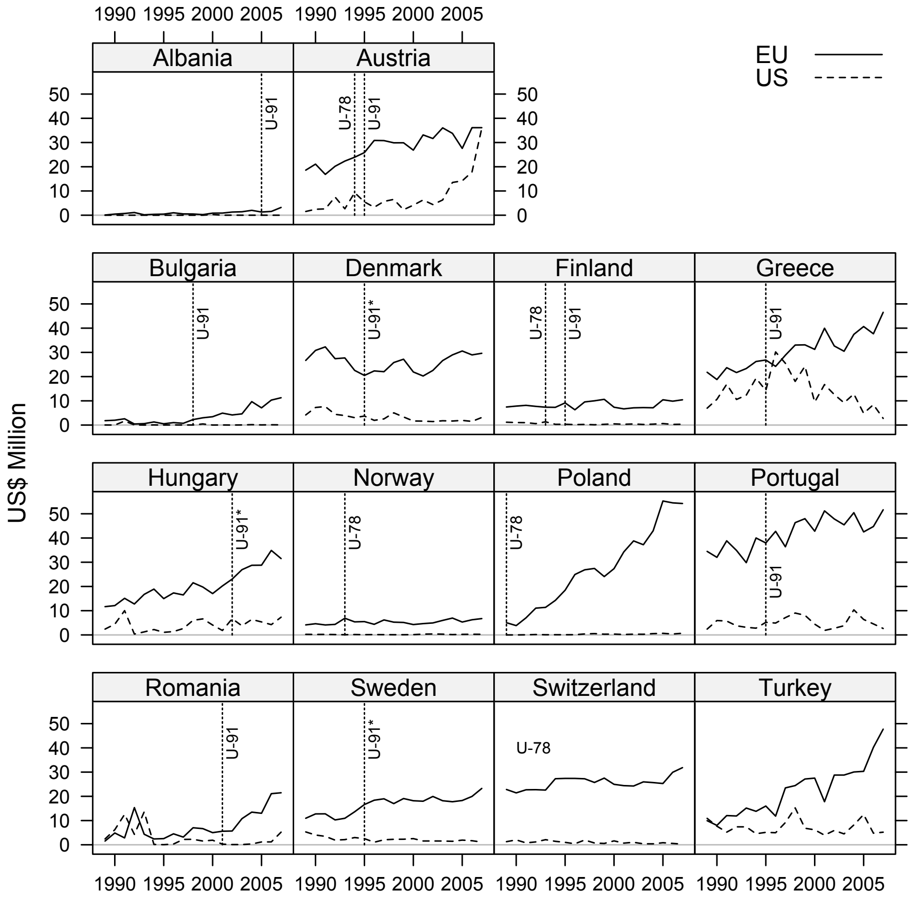


Figure 4.3: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 3 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

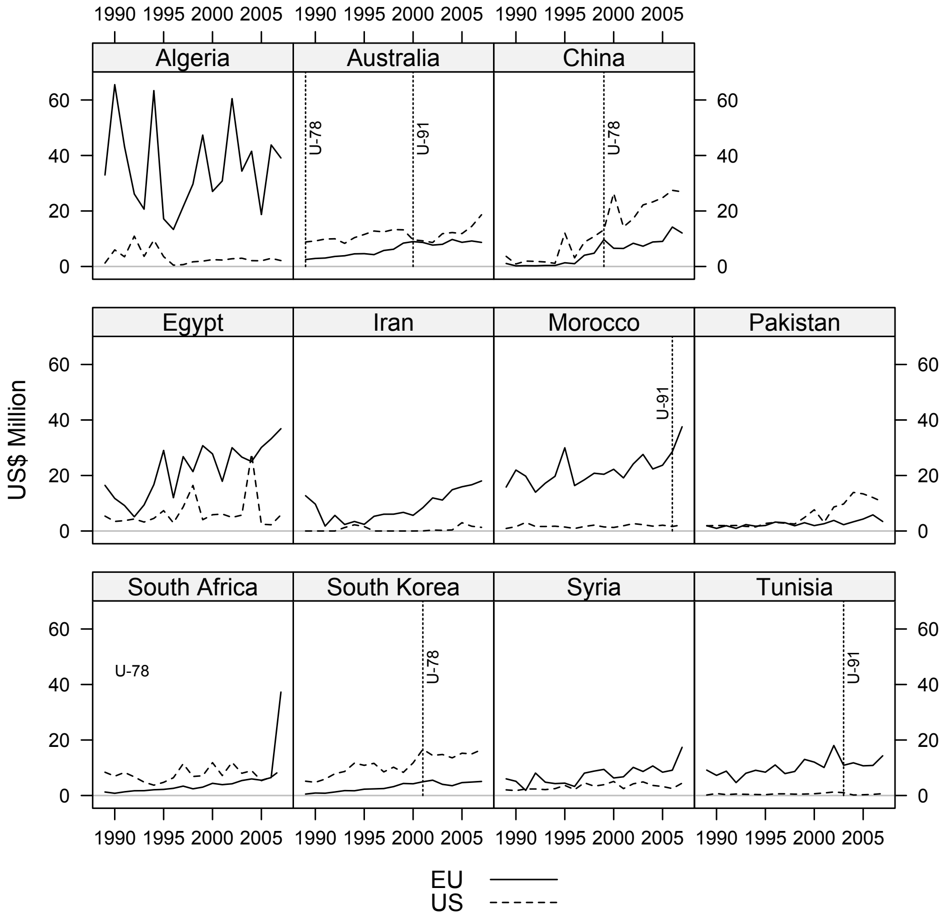


Figure 4.4: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected Latin American countries (1989-2007) - Group 4 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

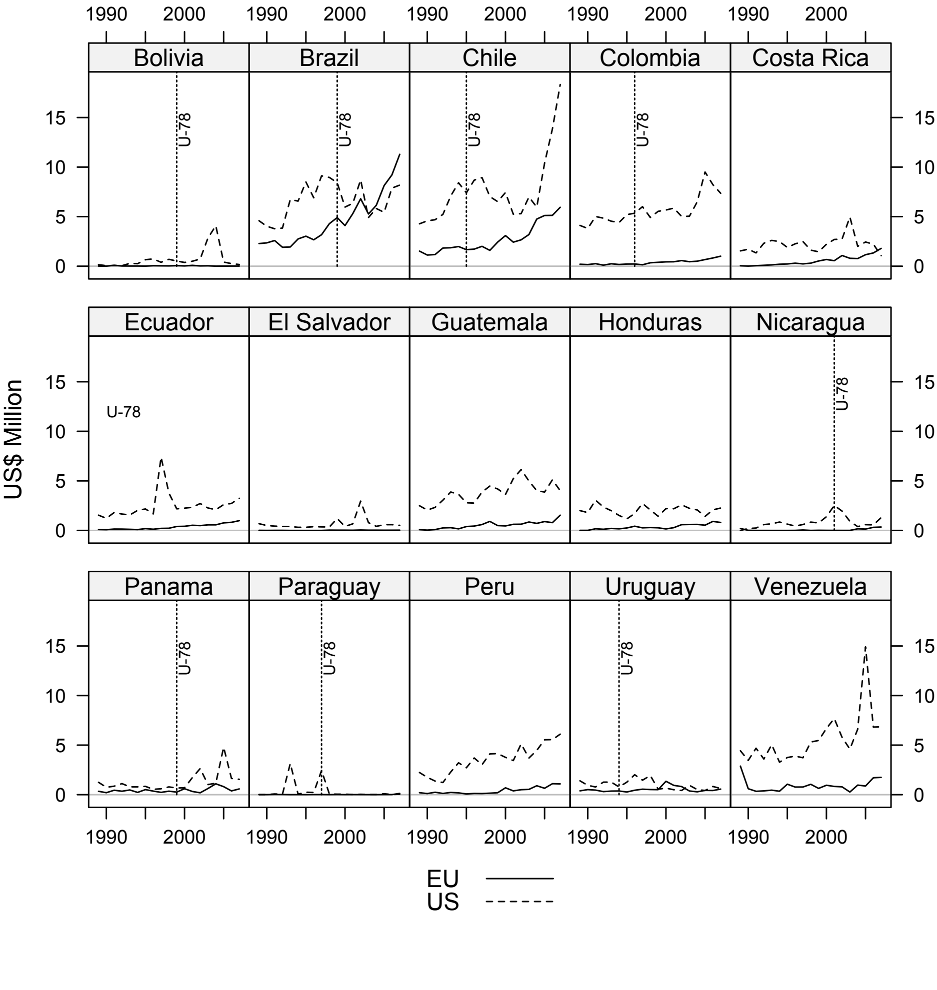


Figure 4.5: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 5 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

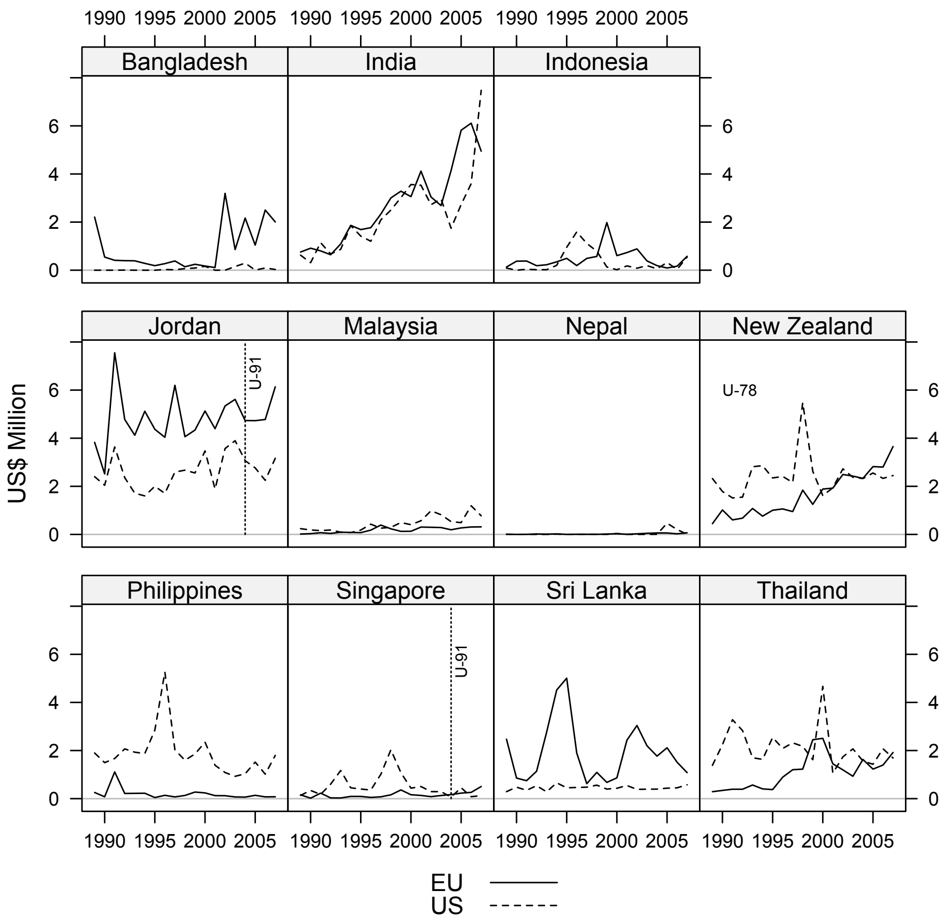
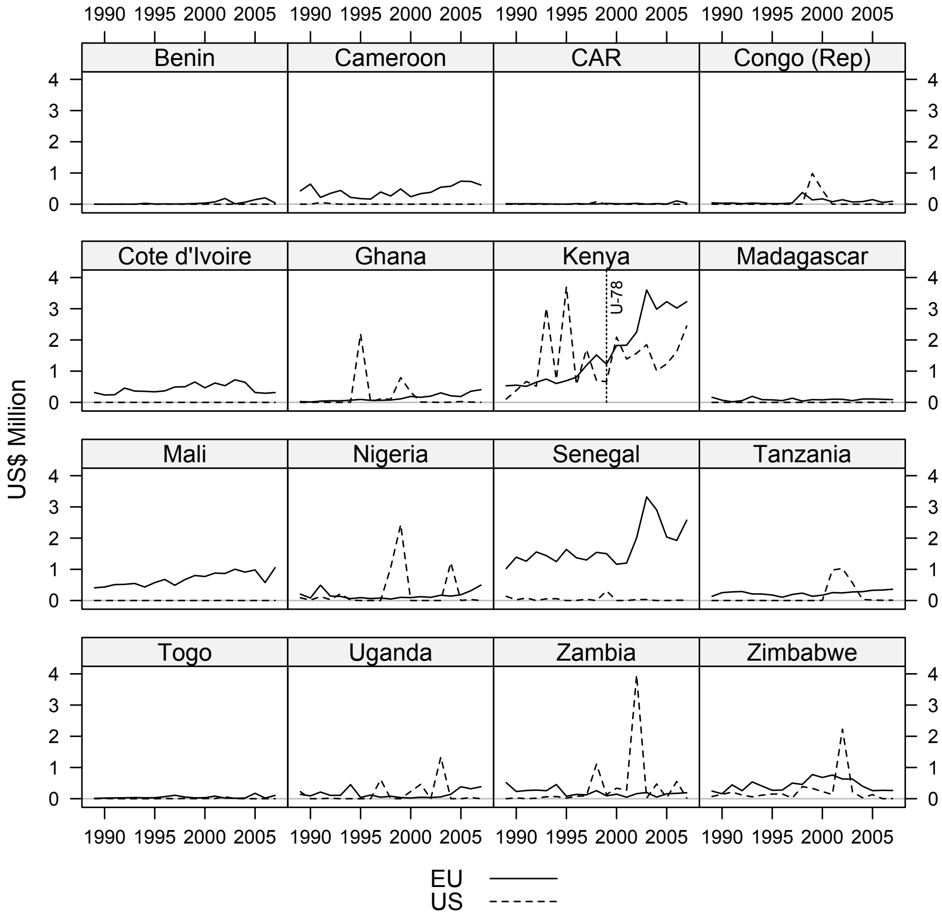


Figure 4.6: Seed imports (constant US$ 2000) from10 EU countries and the US for selected African countries (1989-2007)- Group 6 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)



Many Asian countries had also not yet adopted UPOV PBRs, including Bangladesh, India, Indonesia, Iran, Malaysia, Nepal, Pakistan, the Philippines, Sri Lanka and Thailand (Figure 4.4 and Figure 4.5).[13] Some of these countries, such as Bangladesh, Malaysia and Nepal have marginal seed imports, but others, such as India, Iran and Pakistan, have experienced steadily increasing seed imports. Among Asian UPOV-member countries, China and South Korea show patterns somewhat similar to Chile and Colombia: rising seed imports throughout the 1990s prior to the adoption of the 1978 Act, without no apparent increase in seed imports in the short period immediately thereafter.

For almost all of Sub-Saharan Africa (Figure 4.6), seed imports really are in value.[14] Kenya and South Africa (the latter shown in Figure 4.3) are the principal exceptions, with the East African country importing considerable seed and planting material for its growing horticultural sector. Kenya's imports were increasing prior to the adoption of the UPOV 1978 Act in 1999, which was followed by further steady growth. Although less volatile in the subsequent five years, it is difficult to infer on the basis of such visual analysis alone whether this constituted some sort of structural break. In comparison to other countries in the region and the rest of the continent, Kenya's experience does not suggest though that UPOV membership has 'kick-started' seed imports, and other factors have likely played a more important role. The comparison with Uganda is relevant given the growth in the horticultural sector experienced there since the mid-to-late 1990s. While the low seed imports for this country could be interpreted as reflecting the proposition that seed imports will remain low without IPR protection, it seems more plausible that other factors play a greater role in making Uganda less attractive an export destination than Kenya, and these factors were already at play before Kenya joined UPOV. South Africa, is not really comparable in economic terms to the rest of Sub-Saharan Africa. The country's seed imports are considerably higher, showing also an upwards trend. As the country adopted the UPOV 1978 Act earlier, the comparison with surrounding countries of southern Africa may support an interpretation that PBRs are one of the relevant differences supporting a more productive agricultural sector in South Africa (but other factors again need to be accounted for, as will be attempted in the subsequent sections).[15]

In general then, the figures do not suggest very strong evidence for a positive incentive effect from PBRs on the export of seeds to adopting countries. The subsequent sections attempt to examine this data more systematically using panel data methods,

[13] India stands out as having not chosen the UPOV PBR model legislation; instead, after considerable debate, the country crafted its own version of PBR protection that also includes provision for the protection of farmers' varieties.

[14] The sixteen countries of the African Intellectual Property Organization (AIPO, but often referred to by its French acronym, OAPI, as its membership consists primarily of francophone countries of West and Central Africa; see `http://www.oapi.wipo.net/en/OAPI/historique.htm`) agreed to implement UPOV 1991 as part of the revised Bangui Agreement with the EC of 1999. The legislation establishing PBRs only took effect on 1 January 2006, and the extent of implementation is still not clear.

[15] Note that peaks in imports in Zambia (1998, 2003) and Zimbabwe (2003) are accounted for primarily by imports of maize seed in the form of food aid.

controlling not only for other factors, but also for unobserved heterogeneity among importing countries.

Table 4.7 and Table 4.8 (found in the Annex) present all 79 countries according to seed imports per year ranked by quintile for each of the exporters respectively. This is helpful in interpreting the results below where we apply quantile regression methods. As suggested by the figures above, it can be seen that some countries progress over time as their seed imports grow (e.g. China and India), also relative to other countries, and so appear in three or even four quantiles. Some other countries appear in only one quantile, particularly towards the high end of the distribution, highlighting the logistic nature of the sample distribution.

4.3 Empirical modeling of seed imports

Our model, like that of Yang and Woo (2006), is partly based on the gravity model, which was developed to explain the pattern of aggregate bilateral trade flows in a general equilibrium setting (for example, Anderson and van Wincoop, 2003). The gravity model explains these flows as a function of the relative size of economies, their distance from each other and factors affecting the cost of trade, such as tariffs, nontariff barriers, etc. Here we are concerned however with modeling trade in only one particular sector. Other recent applications of the gravity model to the food and agriculture sector include papers by Amponsah and Ofori Boadu (2007), Jayasinghe and Sarker (2008), and De Frahan and Vancauteren (2006), who analysed the effect of harmonised food safety regulations on intra-EU trade in 10 different food products, each of which was estimated as a separate equation, allowing the estimation of specific structural parameters of the gravity equation.[16] At a sectoral level, the gravity model also incorporates the respective sector's output in exporting countries and expenditure in importing countries. The focus here is on trade in seed and planting material and in particular how this trade has been affected by the introduction of PBRs in various countries in recent years.[17]

The basic model for imports M of country i from country j of product or sector k is as follows (Anderson and van Wincoop, 2003):

$$M_{ijk} = \frac{E_{ik}Y_{jk}}{Y_{wk}} \left(\frac{T_{ijk}}{P_{ik}P_{jk}}\right)^{1-\sigma_k} \tag{4.1}$$

where Y_{wk} is the world output for sector k, Y_{jk} is the output of product k produced by exporting country j, E_{ik} is the expenditure in importing country i on product k, T_{ijk}

[16] Earlier applications to food and agriculture include papers by Koo et al. (1994) and Dascal et al. (2002).

[17] From a theoretical perspective, an alternative would be to specify a structural partial equilibrium model for the good concerned, including all relevant bilateral trade flows. This approach is faced though with considerable data requirements and estimation difficulties. It is likely to be feasible only when the number of trading countries is fairly limited. In the end, a modified gravity equation resembles a fairly simple reduced-form of the underlying partial equilibrium model.

represents a trade cost factor, P_{ik} and P_{jk} are price indices incorporating multilateral trading barriers, and σ_k is the elasticity of substitution between different exporters of product k. As in De Frahan and Vancauteren (2006), the trade cost factor T_{ijk} can be expressed as,

$$T_{ijk} = D_{ij}^{\delta_k} \prod_g Z_g^{\theta_{ijk}} \tag{4.2}$$

in which D_{ij} is the distance between countries i and j, which affects trade costs for product k through δ_k, and Z represents a range of g additional variables affecting trade costs, such as language, adjacency, institutional similarities, and of relevance for our analysis, intellectual property rights (IPRs). Log-linearizing and combining these two equations yields the log-linear gravity equation (dropping the subscript k as there is only one sector under consideration):

$$\begin{aligned} \ln M_{ij} &= \ln E_i + \ln Y_j - \ln Y_w + \frac{\delta}{1-\sigma} \ln D_{ij} \\ &\quad - (1-\sigma)\ln P_i - (1-\sigma)\ln P_j + \frac{\theta_{ij}}{1-\sigma} \sum_g \ln Z_{gi} \,. \end{aligned} \tag{4.3}$$

Incorporating the time dimension, the corresponding estimating equation can be written as

$$\begin{aligned} \ln M_{ijt} &= \alpha_i + \gamma_j + \mu_t + \beta_E \ln E_{it} \\ &\quad + \beta_Y \ln Y_j + \beta_D \ln D_{ij} + \beta_P \ln P_i + \beta_P \ln P_j \\ &\quad + \sum_g \beta_g \ln Z_{git} + \epsilon_{ijt} \end{aligned} \tag{4.4}$$

which includes individual importer and exporter specific effects, α_i and γ_j , respectively to account for potential unobserved heterogeneity, as well as time effects, μ_t , which incorporate any variation in world output (in this sector), Y_w . The estimating equation also reflects some reparametrization, with $\beta_D = \delta/\left(1-\sigma\right)$, $\beta_P = 1-\sigma$, and the vector of coefficients $\beta_g = \theta_{ij}/\left(1-\sigma\right)$. There are some restrictions suggested by this equation, namely that $\beta_E = 1$ and that $\ln P_i$ and $\ln P_j$ have the same coefficient. In addition, (4.3) indicates that the coefficients on trade costs could be heterogeneous across importer-exporter pairs, though this has not generally been incorporated in the empirical literature.

Where the focus of research interest is on specific policy-related measures that vary across countries, it has been common practice in gravity estimation to use a country's GDP as a proxy for the multilateral resistance terms P_i and P_j, with an alternative being to employ time-varying country effects (UNCTAD Virtual Institute, 2012).

This is indeed what we do for the respective importer term, P_i, for which we also follow the example of Yang and Woo (2006) and decompose this multiplicative term into population and GDP per capita. Given the limited number of exporters in the data set, the P_j term is represented by an exporter-specific effect, and a time-varying exporter-specific effect. This implies then that the coefficient on the production of seed in the exporting country, β_Y , is not identified, and that this variable is subsumed in the time-varying, exporter-specific effect. This can be justified by the lack of observable data on Y_j for the seed sector.

Furthermore it is noted now that expenditure on seed in importing countries is not generally observed and therefore alternative proxy variables will be used below, including the value of crop production, the quantity of fertiliser consumed and agricultural value added (GDP). Regarding trade costs, attention here focuses on country and time-specific dummy variables representing UPOV membership in the 1978 and 1991 versions of the Convention.[18] As in the case of Yang and Woo (2006), it is assumed that a lack of IPRs contributes to trade costs. Without IPRs, exporters face higher costs in terms of measures that need to be taken to ensure protection of their intellectual property in foreign markets. It may even be that the large degree of uncertainty in certain countries implies such high transaction costs that exporters elect not to participate in those markets at all. The introduction or strengthening of IPRs is hypothesized to reduce such costs and thus lead to greater trade in seed. Other relevant trade cost variables could include tariff or non-tariff barriers (such as SPS measures relevant to seed imports (as in Jayasinghe, Beghin and Moschini, 2010)). The existing global databases of tariffs, TRAINS and WITS, do not though contain comprehensive coverage of tariffs for the seed sector that includes time variation, meaning that such a variable is also not identifiable.[19] A generic trade cost variable of relevance that is included is an importing country's currency exchange rate relative to the exporting country. Further discussion on data availability is found below in section (sec. 4.4).

With all these considerations, the estimating equation can then be written as

$$\begin{aligned} \ln M_{ijt} = {} & \alpha_i + \gamma_j + \varphi_{ij} + \mu_t + \nu_{it} + \pi_{jt} + \beta_E \ln E_{it} \\ & + \beta_D \ln D_{ij} + \beta_{POP} \ln POP_{it} + \beta_{GDP} \ln (GDP/cap)_{it} \\ & + \beta_{EX} EX_{ijt} + \beta_{U78} UPOV78_{it} + \beta_{U91} UPOV_{it}91 + \epsilon_{ijt} \end{aligned} \tag{4.5}$$

This three-way specific effects structure follows the findings of Baltagi, Egger and Pfaffermayr (2003) who highlight the importance of including the interaction effects and indeed these terms correspond to variables in the theoretical equation (4.3). In

[18] Recalling from above that membership in such a Convention implies that relevant legislation has been enacted.

[19] TRAINS: Trade Analysis and Information System, developed by UNCTAD; WITS: World Integrated Trade Solution, developed by the World Bank; see ihttp://http://wits.worldbank.org. Note also that a method would have to be developed to aggregate tariffs across seeds of different crops, such as through the use of some weighting procedure.

general, it is expected that all of the explanatory variables will have positive coefficients, with the exception of distance, D_{ij}, and the exchange rate, EX_{ijt} (expressed as local currency units per foreign currency), which should have a negative effect on seed imports.

Estimation of (4.5) can be undertaken by standard linear panel data techniques assuming fixed or random effects, with corresponding assumptions on the possibility of correlation between ϵ_{ijt} and the specific effects, (α_i, γ_j, μ_t, ν_{it}, π_{jt}). Although the analysis of Yang and Woo (2006) had only one exporter (US), they clearly rejected a random effects formulation with a Hausman test. Based on the presentation of the full dataset above, the level of heterogeneity among countries does indeed suggest a fixed effects model as the most plausible assumption (which is also confirmed by testing discussed in the results below).[20] In addition, our primary interest is in the effect of time-varying variables, in this case UPOV membership. However, as was seen in sec. 4.2, for many countries UPOV membership does not change over time. Thus, a fixed effects (using a within estimator) procedure will effectively ignore the variation in seed imports correlated with UPOV membership for cases where the later remains constant. For example, in our sample, there are 20 out of 56 countries without UPOV membership at all, and 34 that never join UPOV 1991 during the course of the period studied. There are 13 countries which were already members of UPOV 1978, only some of which join UPOV 1991 during the period studied. This suggests the use of the Hausman-Taylor instrumental variables estimator, which will still incorporate both within and between variation.

One challenge to estimating the log-linearized gravity equation for disaggregated data that has been identified in the literature concerns the treatment of observations of zero trade flows for which the logarithm is not defined (UNCTAD Virtual Institute, 2012). Earlier analysis tended to take the logarithm of the observation plus one, though as demonstrated by Santos Silva and Tenreyro (2006), this can lead to biased estimation, particularly if the proportion of zero observations is substantial. In our dataset, there are only two observations of zero among exports from the 10 European countries but more than 100 for US exports. These authors proposed estimating the level of imports using Poisson quasi-maximum likelihood estimation (QMLE), thus avoiding the logarithmic transformation. The advantages of QMLE were recently verified and extended by Henderson and Millimet (2008). Another approach is the use of sample selection, two-part or hurdle models, as implemented by Helpman, Melitz and Rubinstein (2008), Koop, Poirier and Tobias (2007, pp. 240-2) and Ranjan and Tobias (2007). The issue has been reviewed at length from the standpoint of the applied analyst by UNCTAD Virtual Institute (2012) who point out that the best approach may depend on the context and the research question at hand. A traditional log-linear panel data approach will treat the zero observations as missing

[20] To assume that individual effects are uncorrelated with the error term has little interpretation in a situation, such as with the gravity model, where one cannot substantiate such an assumption in terms of sampling from a larger population. With this type of cross-country analysis, which incorporates essentially the entire population of interest, the individual effects are more than likely to be correlated with unobserved variables, for example, and such reasoning can be motivated by appealing to arguments of heterogeneity among countries and even historical path dependence.

values, which could reflect measurement error.[21] Sample selection or two-part models separate the likelihood of trade (the extensive margin) from its scale (the intensive margin) and identification clearly requires an additional variable to explain selection but which is restricted from the second equation. The Poisson QMLE approach does not ignore zero observations but explains these in the same manner that it does positive trade flows. Returning to the basic gravity model (4.1), a zero flow could only be explained by zero expenditure in the importing country. In the analysis below, we apply log-linear panel techniques (ignoring zeros) and also Poisson QMLE since there is no clear variable available to distinguish between selection and the level of trade for the seed sector. However, the level of heterogeneity in the data, which will also be demonstrated in the results below, leads us to apply quantile regression techniques and the following subsection summarizes recent developments in panel quantile regression techniques.

4.3.1 Penalized quantile regression for panel data

In addition to conditional mean analysis, applying standard fixed and random effects approaches to the static model, discussed above and as undertaken by Yang and Woo (2006), we also apply quantile regression techniques to the panel data model. This permits a more thorough analysis of the data, in particular accounting for heterogeneous relationships between explanatory variables and different levels of seed imports. This might possibly reveal a statistically significant relationship in only part of the sample that would not be detectable by conditional mean methods. Alternative approaches to incorporate cross-sectional heterogeneity include the variable coefficient GLS estimator due to Swamy and Arora (1972) mixed effects models estimated with ML, which are more common in the statistical literature (Cameron and Trivedi, 2005), and Pesaran's (2006) common correlated effects mean group estimator. The quantile regression offers some advantages in terms of computatinal robustness and in making fewer distributional assumptions. In addition, quantile regression has recently been extended to dynamic panel data models, which will be relevant in this application.[22]

Quantile regression for panel data with specific effects was developed by Koenker (2004; 2005), and has been applied by Lamarche (2008) to educational attainments. For a basic panel data model, such as

$$y_{it} = \alpha_i + x'_{it}\beta + u_{it} \quad i = 1, .., N \quad t = 1, ..., T_i \,, \tag{4.6}$$

where y_{it} is observation on the dependent variable (here seed imports, $\ln M_{ijt}$) for cross-sectional group i (importing country) at time t, observations on the explanatory variables are the vector x_{it}, the (importing country) fixed effects are α_i, which

[21] Trade data is generally truncated at Euro 1,000 or US$ 1,000 and thus a zero may still reflect a positive value.

[22] Aside from these considerations, the choice of the quantile regression framework means that the problem of Jensen's Inequality in taking logarithms of expectations, as explained by Santos Silva and Tenreyro (2006), is avoided.

corresponds to a specific intercept (location shift) for each importing country, and u_{it} is the stochastic error term. The corresponding quantile regression model is

$$Q_{y_{it}}\left(\tau|x_{it},\,\alpha_i\right)=\alpha_i+x_{it}'\beta\left(\tau\right)\quad i=1,...,N\ t=1,...,T_i\ , \tag{4.7}$$

where $Q\left(\tau|\ \right)$is the conditional quantile function for quantile τ $(0<\tau<1)$.[23] The quantile regression model specifies the coefficients γ, β as possibly varying per quantile and these are therefore a function of τ. The parameters α and β can be estimated by

$$\underset{\alpha,\beta}{\operatorname{argmin}}\sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N}\rho_\tau\left(y_{it}-\alpha_i-x_{it}'\beta\left(\tau_k\right)\right)+\lambda\sum_{i=1}^{N}|\alpha_i| \tag{4.8}$$

where ρ_τ is the standard quantile loss function and k indexes the quantiles τ. In terms of estimation procedures, Koenker has developed an algorithm to solve the optimization problem in 4.8, making use of sparse linear algebra and interior point methods and available for implementation in `R`.[24] Following the example of Lamarche (2008)[25], we use the panel bootstrap to estimate confidence bounds for the estimator, sampling with replacement over the importing countries.[26]

This estimation proposed by Koenker (2004) also includes a penalty function $\lambda\sum_{i=1}^{N}|\alpha_i|$ as an additional term to reduce bias arising from the estimation of the incidental parameters, α, which can be specified to reflect different assumptions on α. Unlike the standard linear fixed effects models, it is not possible in the quantile regression framework to eliminate α_i through a transformation, such as demeaning or differencing. As explained by Koenker (2004), this means that this penalized fixed effects estimator is more analogous to the random effects estimator in the conditional mean framework, than to the fixed effects (within) estimator which only incorporates variation among groups. The penalized fixed effects quantile regression thus incorporates variation both within and between groups, which is quite relevant for our dataset in which a number of countries do not change their status of UPOV membership during the sample period.[27] The selection of the optimal value of the penalty parameter λ is undertaken following an information criteria as described in Koenker (2004; 2010), following Machado (1993) and Koenker, Ng and Portnoy (1994).

The penalized form makes it possible and relatively convenient to incorporate more complicated specific effects structures, such as a two-way panel specification that

[23] The conditional quantile function is defined as $Q_Y\left(\tau|X\right)=\inf\left\{y\ :\ F_{Y|X}\left(y\right)\geq\tau\right\}$ where $F_{Y|X}$ is the conditional distribution function of Y given X, and τ is conventionally used to designate the quantiles over the interval $(0,1)$.

[24] The program code is incorporated in the `quantreg` package (Koenker, 2008) for `R` (R Core Development Team, 2012).

[25] And as recommended by Koenker (`http://www.econ.uiuc.edu/~roger/research/panel/rq.fit.panel.R`).

[26] We report results for 400 bootstrap replications.

[27] In this regard, the term "fixed effects" is potentially misleading.

includes penalized time effects:[28]

$$y_{it} = \alpha_i + \mu_t + x'_{it}\beta + u_{it} \quad i = 1, .., N \quad t = 1, ..., T_i \,, \tag{4.9}$$

with the corresponding quantile regression model,

$$Q_{y_{it}}\left(\tau | x_{it},\, \alpha_i,\, \mu_t\right) = \alpha_i + \mu_t + x'_{it}\beta\left(\tau\right) \quad i = 1, ..., N \; t = 1, ..., T_i \,. \tag{4.10}$$

This can be estimated by

$$\underset{\alpha,\beta}{\operatorname{argmin}} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} \rho_\tau\left(y_{it} - \alpha_i - \mu_t - x'_{it}\beta\left(\tau_k\right)\right) + \lambda_\alpha \sum_{i=1}^{N} |\alpha_i| + \lambda_\mu \sum_{t=1}^{T} |\mu_t| \tag{4.11}$$

in which there are two penalty parameters, λ_α and λ_μ , corresponding respectively to the country-specific effects and the time period effects.

The fixed effects quantile regression and its penalized variant have recently been extended to a dynamic linear panel data model by Galvao (2011), who has applied this estimation technique to cross-country output growth rates and separately to firm capital structure adjustment (Galvao and Montes-Rojas, 2010). In the case of the the basic dynamic panel data model with one lag for the dependent variable,

$$y_{it} = \alpha_i + \mu_t + \gamma y_{i,t-1} + x'_{it}\beta + u_{it} \quad i = 1, .., N \quad t = 1, ..., T_i \,, \tag{4.12}$$

The corresponding dynamic fixed effects quantile regression model is

$$Q_{y_{it}}\left(\tau | x_{it},\, \alpha_i,\, \mu_t\right) = \alpha_i + \mu_t + y_{i,t-1}\gamma\left(\tau\right) + x'_{it}\beta\left(\tau\right) \quad i = 1, ..., N \; t = 1, ..., T_i \,. \tag{4.13}$$

Estimation is as with (4.8), but now with minimization taking place over γ as well. Galvao and Montes-Rojas (2010) find through Monte Carlo evidence that the penalty term reduces the dynamic panel bias and increases the efficiency of the dynamic fixed effects estimators. Improved performance is also found relative to instrumental variables quantile regression estimation, as proposed by Chernozhukov and Hansen (2008) and Galvao (2011), which extends the instrumental variables approach of Ahn and Schmidt (1995) and Blundell and Bond (1998) to the quantile regression framework. Galvao and Montes-Rojas (2010) note that the instrumental variables approach to reducing dynamic bias performs less satisfactorily as the autoregressive parameter γ increases towards one and also as the variability of the fixed effects increases, both of which turn out to be relevant considerations in our application.[29] The penalty

[28] In a conventional fixed or random effects setting, these time effects are often introduced simply as dummy variables (Cameron and Trivedi, 2010), but with longer panels such as ours, this could also lead to incidental parameter bias.

[29] This poor performance was also evident in preliminary work using the system GMM procedure.

selection is undertaken with $\tau = 0.5$, as done by Galvao and Montes-Rojas (2010), following Machado (1993).

A dynamic panel formulation permits an assessment of possible state dependence and a check on possibly omitted time-variant heterogeneity. Yang and Woo (2006) also found evidence for the inclusion of lagged seed imports in their model of US data, which seems reasonable based on graphical inspection of the data above. In their analysis, exclusion of lagged imports resulted in substantial omitted-variables bias that could even support erroneous inferences on the significance of UPOV membership. The dynamic fixed effects quantile regression may offer some robustness advantages relative to the conventional approach in a conditional mean setting. Blundell, Griffith and Windmeijer (2002) note, for example, that system GMM applied to the dynamic count data model (corresponding to panel data Poisson regression discussed above) may only work reasonably well in datasets with high signal-to-noise ratios and where the time dimension is fairly limited relative to the cross-section dimension. They demonstrate that their GMM estimator is likely to be severely biased, particularly in small samples and with 'persistent' regressors that change little over time. Nonetheless, the theoretical gravity model does not suggest a dynamic formulation, and so we do also include results for a static model, for illustrative purposes.

4.4 Data

This section describes the additional data used to estimate (4.5). Explanatory variables include population, GDP per capita and exchange rates, which are all taken from the World Bank's World Development Indicators database[30], as well as distance between the exporting and importing countries, which is taken from the CEPII GEODIST database commonly used for gravity models.[31]

For E_{it} , total annual expenditure on seeds in the importing country, there are however no generally available statistical series on commercial seed sales, even for many developed countries. As a principal proxy, the value of crop production, which is available in FAOSTAT is taken.[32] It seems plausible that there is a direct correlation between this and expenditure on seed, as all crop production requires seed. As a country's agricultural market becomes further commercialized, crop production increases and particularly in value terms as subsistence crops may be substituted by higher-value crops or cash crops, including export crops. This process of commercialization generally involves the development of a seed market, as farms increasingly

[30] `http://www.worldbank.org/wdi`. All monetary variables are taken in constant US$ with 2000 as the base year, as was done with the data on agricultural seed imports.

[31] `http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=6`. For imports from the 10 European exporting countries, the distance from Belgium is chosen as this is equidistant between the two principal exporters, France and the Netherlands. The principal interest of the research lies in the imports to countries outside of this core group of seed producers and exporters (as well as the US). Thus, it is the distances to countries in Africa, Latin America and Asia that will play the largest role in the analysis and the relative values of these distances are not generally affected by the choice of Belgium versus some other average of distances to all 10 exporting countries.

[32] Also in constant US$ 2000 dollars; `http://http://faostat.fao.org/`

purchase seed from suppliers, rather than save seed from previous harvests. For new, higher-value crops, farms are obliged to purchase such seed. The lack of data on commercial seed sales makes it however not possible to justify this proxy variable with some indicative correlations. We therefore include an additional proxy variables for E_{it} , the amount of chemical fertiliser consumed in a country (metric tonnes and also taken from FAOSTAT).[33] It seems plausible that the process of commercialization of the seed market and its growth is correlated with the increased use of other inputs in crop production, of which fertilisers are one of the most important. This suggests the use of fertiliser consumption as a proxy variable for expenditure on seeds. Data is available in FAOSTAT for 56 countries on these two proxy variables, which is the constraining variable on the size of our sample as data on seed imports is available for almost 80 countries. For this reason, we also undertake some additional analysis using agricultural GDP as a proxy for expenditure on seeds, as this is available for a wider selection of countries.[34] Agricultural GDP is fairly correlated with the value of crop production and generates similar results, as will be seen below.[35]

The representation of UPOV membership is fairly straightforward with two dummy variables, *UPOV78* and *UPOV91*, taking on values of 1 if an importing country was a signatory of the UPOV 1978 Convention, or 1991 Convention respectively, at time t and zero otherwise. As the 1991 Convention implies broader scope of protection, if a country signs this version without first having become a member of the 1978 Convention, then *UPOV78* is also set to 1 from that point onwards; thus, the *UPOV91* variable represents the incremental effect of membership of the 1991 Convention relative to the 1978 Convention. Note that this distinction was not incorporated in the study by Yang and Woo(2006).

Ideally it would be desirable to include a variable that reflects the quality of the PBRs offered by a country. Membership of a UPOV Convention means that the country has enacted corresponding legislation and is offering PBR certificates upon consideration of a successful application by plant breeders. There may though be differences in the extent to which, or efficiency with which PBR holders can successfully defend those rights, by pursuing suspected infringers through legal mechanisms (e.g. Tripp, Louwaars and Eaton, 2007). Yang and Woo (2006) considered using years of UPOV membership but reasoned that this is too rough a proxy of strength of protection. They did include dummy variables for membership of the Paris Convention and the TRIPS agreement as indicators of IPR protection in general. The latter does not arguably contribute much additional information though since TRIPS membership follows automatically from WTO membership; in Yang and Woo's dataset, 54 out of 60 countries joined WTO/TRIPS in 1995.

[33] We also undertake regressions (not presented) using an additional possible proxy for expenditure on seeds, the amount of chemical fertiliser imported, with largely the same results. Although a less convincing proxy, fertiliser imports are also included since this might be even more correlated with seed imports; a country that uses more fertiliser but is required to import a greater portion of consumption rather than produce it domestically, may also increasingly import more seed.

[34] Available in the World Development Indicators database, also in constant US 2000 dollars.

[35] Correlation coefficient = 0.94. In exploratory work, we also examined agricultural GDP per hectare and per worker as possible complementary explanatory variables and proxies for expenditures on seeds; these were however not adding any new dimensions of correlation to seed imports.

An alternative variable that is commonly used in the literature is the Ginarte and Park index of IPR protection (Ginarte and Park, 1997; Park, 2008).[36] This index is based on a sum of five separate indices, one of which is membership in IPR treaties or conventions, of which UPOV is one. The other subindices consist of the coverage (patentability of subject matter), measures for loss of protection (such as compulsory licensing), enforcement mechanisms and the duration of protection. These subindices are each calculated using objectively verifiable binary questions. However, the process of summing up such questions, both within and across subindices means that the index is not based on a uniform measurement scale. Its direct use in regression techniques is therefore not legitimate.[37] Similar problems arise in considering the use of other indices such as the index of property right protection, compiled in the Economic Freedom of the World database.[38]

The dynamic models estimated below, with lagged values of *UPOV78* and *UPOV91*, do allow the possibility that there could be some delay between a country signing the UPOV agreement, including enacting necessary legislation, and then fully implementing a PBR system. In addition, it is quite possible that the quality of the exclusive rights might not be optimal at the immediate outset but instead develop over time, as applications are filed and approved, and subsequently challenges are brought through the appropriate legal mechanisms. The perceived quality of the PBRs, as a protection mechanism, can be expected to be strongly reinforced once plant breeders can observe the effective enforcement of these rights. In general, it can be expected that the recognition and economic importance of PBRs as a new form of exclusive right will require a certain amount of institutional and behavioural change.[39]

Summary descriptive statistics are provided in Table 4.1. Annual imports of seeds range from US$ 1,000 to US$ 311 million. The mean is US$ 28 million while the median is only about US$ 5 million, indicating a left-skewed distribution, whose logarithmic transformation is almost centred. The database contains a reasonable amount of variation in terms of whether the importing country is a signatory of the UPOV 1978 treaty in each period (35% of observations), with somewhat less than one-half of those cases (16% of all observations) also reflecting membership of the broader 1991 version.

[36] Studies applying this index include for example Co (2004); Smith (1999).

[37] A difference of, for instance, 0.1 in what part of the index is not necessarily equivalent to such a difference elsewhere in the scale of the index. Furthermore, Park (2008) notes that the index is intended to provide an indicator of the strength, or scope, of patent protection, not an indicator of the quality of patent protection, or even other IPR systems.

[38] Available at `http://www.fraserinstitute.org/researchandpublications/publications/6194.aspx`

[39] Experiences in the extension of IPRs to the digital domain (e.g. music, software) offer a more broadly appreciated illustration of the nature of these changes and the time that may be involved in their implementation and institutionalization.

Table 4.1: Summary statistics

	Mean	Median	Std. Dev.	Min	Max
Total seed imports (US$ million)	34.67	8.63	58.60	0.1	287.0
Seed imports from EU (US$ million)	22.27	3.59	45.67	0	276.7
Seed imports from US (US$ million)	12.40	2.44	28.92	0	255.6
Population (million)	83.45	25.97	206.11	3.0	1317.9
GDP per capita (US$)	8,594	2,958	10,4621	274	41,901
Distance from EU (km)	5,903	5,822	4,384	173	19,012
Distance from US (km)	8,231	7,623	3,672	548	16,180
Agric. value added (US$ billion)	16.42	6.18	29.44	0.2	238.3
Value crop production (US$ million)	17,709	5,488	38,602	203	338,268
Fertiliser consumption (nutrient tonnes)	2,196	485	5,760	5	51,162
Fertiliser imports (nutrient tonnes)	883	329	1,646	1	10,515
Exchange rate (US$)	104.20	90.44	156.36	17.7	3,682.2
Member UPOV 1978 (0, 1)	0.45	0.00	0.50	0	1
Member UPOV 1991 (0, 1)	0.20	0.00	0.40	0	1

Notes: Seed imports from 10 European countries (Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, the UK) are extracted from the Eurostat trade database and imports from the US from the database compiled by the Foreign Agricultural Service of the US Department of Agriculture (`http://www.fas.usda.gov/data`). Population, GDP per capita and agricultural value added (all in constant US$, base year: 2000) are from the World Bank's World Development Indicators database, as is the exchange rate. Value of crop production (in constant US$, base year: 2000), fertiliser consumption and fertiliser imports (nutrient metric tonnes for the latter two) are taken from the FAOSTAT database of the Food and Agriculture Organization of the United Nations. UPOV membership data is taken from official documents available at the organization's website (www.upov.org).

4.5 Results

Our preferred specification is a dynamic model, estimated separately for EU[40] and US exports, with two lags of the dependent variable, seed imports, and also of a majority of explanatory variables. The justification for disaggregating exports is based on a rejection of their poolability. The dynamic specification is preferred due to clear evidence of nonstationarity. Furthermore, we focus our discussion on results from the quantile regression, given also a rejection of poolability of seed imports across different countries. These considerations and supporting evidence are discussed below in sec. 4.5.1 and sec. 4.5.2 respectively.

The dynamic version of the model is an autoregressive distributed lag specification that includes two lags for the seed imports, based on results of Westerlund cointegration tests which never rejected the hypothesis of cointegration when more than two

[40] Recall from sec. 4.2 that this refers to exports from the 10 principal exporting EU countries (Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, the UK) but for convenience purposes, this is referred to as "EU" exports.

lags were included (in either EU or US exports; see below).[41] First and second-period lags are also included for explanatory variables to the extent possible, which means variables for GDP per capita, exchange rate, and the UPOV variables. The inclusion of lags of the variables representing population, the value of crop production and fertiliser consumption all lead to collinearity problems, and since these variables do not play an important role in explaining seed imports in simpler model specifications, their values are included only for the current period. The inclusion of the lagged values of the UPOV variables also has a structural interpretation. There may be a delay between a country becoming a UPOV member and the point at which the implemented PBR system is judged by plant breeders to be effective (e.g. Tripp et al., 2007). Similarly, there could be a structural interpretation to the effects of lagged values of exchange rates. These exhibit more volatility and an importer's decision to purchase foreign seeds may be taken well in advance of actual shipment taking place.

The results are presented in Table 4.2 and Table 4.3 for exports from the 10 EU countries and the US respectively. To aid in interpretation, tables detailing the location of importing countries in the quantiles for each exporter are provided in Table 4.7 and Table 4.8 of sec. 4.7.1. Considering first the results for the EU exports, this yields very few coefficients that are estimated to be significantly different from zero at 95% confidence level. All of the estimates on both lagged values of seed imports are though signicantly greater than zero, and their 95% confidence intervals are relatively narrow. There is some mild heterogeneity with estimates for the first lag, decreasing across quantiles, and those for the second lag, increasing, suggesting more persistence of seed imports in countries with higher levels of imports, which seems intuitive.

The most striking finding of Table 4.2 is the lack of significant correlation between UPOV membership and seed imports from the EU. This is also the case for seed imports from the US. As can be seen in Table 4.3, only the lagged values of seed imports are found to have coefficient estimates that are significantly different from zero. For the EU, only one UPOV coefficient at one quantile is found to be signficantly different from zero for GDP per capita, and likewise only one for the exchange rate. The coefficient estimate for UPOV 1978 is found to be significantly positive for the lowest quantile estimated, $\tau = 0.1$, with an estimate of 0.23 and a 95% confidence interval of (0.014, 0155), while the estimate on the second lag of this variable is significantly positive, but lower, for $\tau = 0.3$. The first estimate suggests that UPOV 1978 membership might be associated with a higher level of seed imports from the EU of approximately one-quarter, for countries that import very little seed from the EU. Considering Table 4.7 in the Annex, together with Figure 4.1 through Figure 4.6, this might be reflecting the specific situations of Albania, Bulgaria, China, Colombia and New Zealand, which appear to outnumber the countries with seed imports from the EU in the lowest quintile which have experienced reasonable or even strong growth without UPOV 1978 PBRs, such as Costa Rica or Thailand. Notably, there is no significant coefficient estimate for UPOV 1991 membership.

[41] For robustness reasons, the results below were also compared to those from the inclusion of a third lag, and these did not change the interpretation and conclusions.

A robustness test of these results is undertaken by estimating a similar extended dynamic specification on the larger dataset. As explained above in sec. 4.4, data on the proxy variables used for an importing country's expenditure on seed imports (value of crop production and fertiliser consumption) were only available for 56 importing countries, a subset of the larger dataset of 79 countries, presented in sec. 4.2. For this larger group, agricultural GDP was used as a proxy for expenditure on seeds and the dynamic model yielded very similar results. One notable difference is for EU seed exports for which none of the coefficient estimates on UPOV 1978 (nor its lags) was found to be significantly different from zero (see results in sec. 4.7), in contrast to the result described above for $\tau = 0.1$ on the smaller sample.[42] This suggests that the excluded 23 importing countries from the lowest quantiles do not provide any further evidence of a correlation between seed imports from the EU and UPOV 1978 membership. Indeed, as many of these countries are comprised of low-importing countries in Sub-Saharan Africa, they likely also displace many of the countries in the lowest quantile of the smaller dataset. These additional results generally support a finding of a lack of any significant correlation between UPOV membership and seed imports, and indicate that the two significant coefficient estimates found in the smaller sample are not that robust.

Our results generally confirm those of Yang and Woo (2006), who also found no significant effect of UPOV membership on imports of seeds from the US in their analysis of a dynamic model specification. We have though examined the issue in some more detail, through the estimation of more comprehensive dynamic models including additional lags of both dependent and explanatory variables. More significantly, we have also estimated the model for seed exports from 10 EU countries, which are substantially larger than those from the US and appear to follow different patterns (see sec. 4.5.1 below). In general, we find little explanatory power for seed imports in the variables suggested by the gravity equation, although several caveats are noted. One is that we are only able to employ proxies for seed expenditure with little information as to their correlation with the underlying variable of interest. Secondly, as discussed below, it has not been possible to completely rule out the potential presence of a cointegrating relationship between seed imports and other variables. Addressing this second issue will require additional data, particularly in terms of additional years of observations. Nonetheless, the results of our analysis illustrate the difficulty of applying the gravity model to trade at such a specific product level, at which the influence of aggregate level variables is likely to be weaker and observed patterns more likely to be explained by specific variables of interest.

Aside from these caveats, it still seems unlikely that further improvements in data would uncover a more significant correlation between UPOV membership (and implementation) and imports of seeds. Such a relationship is more likely to have emerged in our analysis, even under misspecification, though perhaps not with consistent estimates as to its magnitude. Various explanations can be offered for the lack of signifi-

[42] For robustness purposes, additional comparisons with the larger dataset and using agricultural GDP are made with the static and dynamic models presented above, yielding very similar results. These additional results on the database with 79 importing countries are not all presented, with the exception of those for the static model, which are also included in the Annex.

cant effect of UPOV membership on seed imports. The first and most obvious is that in general the initiation of PBRs has little effect on the decisions of seed companies to export to specific markets. Indeed, it is known that companies employ a variety of strategies to protect their new varieties from being reproduced by others, whether farmers or competing sellers. Perhaps the most important of these is biological protection through the use of hybridization, where technically possible. Another strategy is the use of contracts and carefully-chosen partnerships with growers. In general, these possibilities as well as a range of other factors, including market prospects and country-specific factors, captured in the fixed effects analysis, may be more important in exporters' decision-making than PBRs, or UPOV. This does not necessarily mean however that PBRs have few consequences for appropriability. Rather, the analysis and the dataset (for which many countries have only recently joined UPOV), assesses the effect of initiating PBRs with UPOV membership on seed imports. So while we have effectively no general evidence of an incentive effect at this stage, we cannot on the basis of our analysis rule out the possibility that a system of PBRs will strengthen trade further in the future.

Appropriability strategies, and indeed business models, of plant breeders and seed companies generally differ according to specific crops, or groups of crops. For example, maize and also many vegetable species have been successfully hybridized, allowing breeders to rely less on PBRs than for open-pollinated species such as wheat, or self-propagating species, such as potatoes. For this reason, we also compiled and inspected crop-specific import data. These are presented in Figure 4.7 to Figure 4.18 (see Annex sec. 4.7.3). In general, the lack of a relationship with UPOV membership visible in the aggregate data is to some extent apparent in the crop-specific time-series. For example, exporting and marketing of maize from the US is arguably less dependent on PBR and there are almost no examples of exports of this crop appearing to be positively correlated with UPOV membership. The same appears true for vegetables, although then there are some clear exceptions, such as Brazil and Chile where imports of vegetable seeds from the EU appear to have risen since the adoption of the UPOV 1978 Acts in these countries. The crop-specific imports are useful though in understanding the heterogeneity among countries. Thus, China has seen a steady rise in seed imports since the mid-1990s. The largest portion is accounted for by the import of forage seeds from the US, followed by vegetable seeds from the EU. This indicates that a more comprehensive regression analysis, disaggregated by crop, might reveal some relationship with UPOV membership. Given the lack of satisfactory explanatory power of the gravity model for seed imports aggregated across crops, a crop-specific analysis could be based more on a derived demand approach, such as that recently undertaken by Jayasinghe et al (2010), who modelled US exports of maize and assessed the role of trade costs in terms of tariffs and sanitary and phytosanitary regulations (though not IPRs). Contingent on the availability of data, such an analysis could differentiate between quantity and price of exports, and also take into account crop-specific explanatory variables, such as current production and possibly domestic output prices, integrating an assessment of IPR measures with other important trade costs. This additional data collection and analysis is left for future work.

Table 4.2: Quantile regression coefficient estimates and 95% confidence intervals by quantile for extended two-way dynamic model of seed imports from EU with two lag periods

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-0.827	0.097	0.046	0.621	1.673
	(-2.307, 1.432)	(-1.311, 0.711)	(-0.831, 0.649)	(-0.531, 1.369)	(-0.583, 2.529)
Seed imports (t-1)	0.694†	0.645†	0.636†	0.612†	0.571†
	(0.591, 0.784)	(0.558, 0.739)	(0.567, 0.740)	(0.492, 0.710)	(0.460, 0.675)
Seed imports (t-2)	0.317†	0.337†	0.330†	0.334†	0.350†
	(0.218, 0.419)	(0.249, 0.418)	(0.227, 0.404)	(0.234, 0.460)	(0.247, 0.451)
Population	-0.044	0.010	-0.015	-0.036	-0.018
	(-0.166, 0.072)	(-0.113, 0.059)	(-0.103, 0.050)	(-0.103, 0.053)	(-0.101, 0.100)
GDP/capita	0.229	0.247	-0.175	-0.251	-0.034
	(-1.070, 1.437)	(-0.387, 0.912)	(-0.807, 0.717)	(-1.109, 0.919)	(-1.024, 1.107)
GDP/capita (t-1)	0.769	0.173	0.555	0.120	-0.726
	(-0.878, 3.262)	(-0.631, 1.695)	(-0.741, 1.789)	(-1.276, 1.349)	(-2.191, 1.539)
GDP/capita (t-2)	-0.980†	-0.404	-0.383	0.102	0.720
	(-2.530, -0.032)	(-1.574, 0.108)	(-1.138, 0.282)	(-0.716, 0.497)	(-0.713, 1.279)
Crop prod.	0.039	-0.002	0.016	0.030	-0.008
	(-0.045, 0.131)	(-0.040, 0.095)	(-0.025, 0.077)	(-0.038, 0.071)	(-0.085, 0.084)
Fert. cons.	0.024	0.005	0.019	0.026	0.053
	(-0.045, 0.094)	(-0.032, 0.059)	(-0.019, 0.052)	(-0.027, 0.067)	(-0.057, 0.103)
Exch. Rate	-0.401	-0.222†	-0.204	-0.147	-0.044
	(-1.053, 0.120)	(-0.626, -0.046)	(-0.530, 0.142)	(-0.427, 0.133)	(-0.562, 0.104)
Exch. Rate (t-1)	0.138	0.029	0.191	0.154	-0.061
	(-0.663, 0.892)	(-0.267, 0.610)	(-0.228, 0.647)	(-0.182, 0.633)	(-0.234, 0.960)
Exch. Rate (t-2)	0.240	0.129	0.034	0.012	0.091
	(-0.184, 0.579)	(-0.128, 0.350)	(-0.153, 0.269)	(-0.235, 0.166)	(-0.553, 0.226)
UPOV78	0.230†	0.085	0.064	-0.021	0.126
	(0.014, 0.452)	(-0.115, 0.227)	(-0.096, 0.143)	(-0.164, 0.136)	(-0.213, 0.192)
UPOV78 (t-1)	-0.149	-0.097	-0.117	-0.078	-0.117
	(-0.428, 0.155)	(-0.317, 0.136)	(-0.257, 0.049)	(-0.287, 0.233)	(-0.357, 0.230)
UPOV78 (t-2)	0.112	0.091†	0.090	0.085	-0.077
	(-0.097, 0.304)	(0.008, 0.273)	(-0.013, 0.239)	(-0.156, 0.241)	(-0.231, 0.223)
UPOV91	-0.07	-0.002	0.054	0.089	0.043
	(-0.145, 0.161)	(-0.134, 0.158)	(-0.051, 0.153)	(-0.018, 0.177)	(-0.073, 0.175)
UPOV91 (t-1)	0.140	0.047	-0.052	-0.003	-0.005
	(-0.190, 0.231)	(-0.132, 0.178)	(-0.145, 0.102)	(-0.131, 0.106)	(-0.140, 0.112)
UPOV91 (t-2)	-0.043	-0.060	-0.013	-0.050	-0.001
	(-0.140, 0.138)	(-0.158, 0.011)	(-0.141, 0.018)	(-0.151, 0.059)	(-0.143, 0.112)

Notes: Estimated from a dynamic penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from EU exporting countries (logarithm), for 56 countries over the period 1990-2007. .All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 3 and 12, respectively.

Table 4.3: Quantile regression coefficient estimates and 95% confidence intervals by quantile for extended two-way dynamic model of seed imports from US with two lag periods

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-6.766	-4.185†	-2.372	-1.456	-0.964
	(-15.299, 3.507)	(-8.451, -1.053)	(-5.953, 1.528)	(-5.143, 2.132)	(-9.829, 3.425)
Seed imports (t-1)	0.330†	0.415†	0.476†	0.425†	0.450†
	(0.144, 0.583)	(0.212, 0.661)	(0.273, 0.673)	(0.295, 0.651)	(0.247, 0.610)
Seed imports (t-2)	0.211†	0.304†	0.210†	0.193†	0.219†
	(0.025, 0.413)	(0.074, 0.418)	(0.062, 0.364)	(0.014, 0.328)	(0.041, 0.324)
Population	0.212	0.132	0.060	0.218	0.131
	(-0.332, 1.182)	(-0.095, 0.541)	(-0.173, 0.416)	(-0.128, 0.500)	(-0.29, 0.513)
GDP/capita	0.179	0.880	0.679	0.531	-0.633
	(-2.088, 1.877)	(-0.107, 1.841)	(-0.206, 1.72)	(-0.672, 1.327)	(-2.116, 1.805)
GDP/capita (t-1)	0.795	-0.172	-0.197	0.012	1.381
	(-1.548, 4.420)	(-1.646, 1.311)	(-1.627, 1.159)	(-0.997, 1.450)	(-1.863, 3.079)
GDP/capita (t-2)	-0.408	-0.347	-0.218	-0.196	-0.717
	(-2.488, 1.543)	(-1.302, 0.586)	(-1.297, 0.537)	(-1.154, 0.579)	(-2.014, 1.393)
Crop prod.	0.026	-0.006	0.045	-0.100	0.099
	(-1.051, 0.458)	(-0.399, 0.239)	(-0.311, 0.244)	(-0.366, 0.287)	(-0.35, 0.679)
Fert. cons.	0.158	0.118†	0.100	0.106	-0.047
	(-0.086, 0.837)	(0, 0.467)	(-0.009, 0.351)	(-0.065, 0.304)	(-0.357, 0.213)
Exch. Rate	0.304	0.260	0.099	0.132	0.706
	(-0.481, 1.020)	(-0.082, 1.065)	(-0.32, 1.351)	(-0.379, 1.152)	(-0.585, 1.395)
Exch. Rate (t-1)	-0.214	-0.171	-0.016	-0.069	-0.462
	(-1.279, 0.849)	(-0.805, 0.229)	(-1.073, 0.342)	(-0.995, 0.487)	(-1.229, 1.060)
Exch. Rate (t-2)	-0.093	-0.013	-0.062	-0.089	-0.272
	(-1.023, 0.927)	(-0.395, 0.370)	(-0.265, 0.315)	(-0.486, 0.201)	(-0.969, 0.074)
UPOV78	0.110	-0.078	-0.051	-0.051	0.097
	(-0.301, 0.572)	(-0.235, 0.187)	(-0.259, 0.234)	(-0.248, 0.352)	(-0.280, 1.189)
UPOV78 (t-1)	-0.025	0.147	0.135	0.027	-0.085
	(-0.825, 0.461)	(-0.418, 0.385)	(-0.186, 0.435)	(-0.321, 0.388)	(-1.187, 0.641)
UPOV78 (t-2)	0.021	-0.141	-0.104	-0.096	0.073
	(-0.331, 0.647)	(-0.29, 0.281)	(-0.406, 0.072)	(-0.35, 0.051)	(-0.645, 0.308)
UPOV91	-0.071	-0.018	-0.058	-0.084	-0.066
	(-0.331, 0.206)	(-0.263, 0.172)	(-0.322, 0.187)	(-0.235, 0.208)	(-0.377, 0.262)
UPOV91 (t-1)	-0.387	-0.249	-0.185	-0.055	-0.054
	(-1.179, 0.090)	(-0.763, 0.034)	(-0.508, 0.128)	(-0.526, 0.274)	(-0.438, 0.646)
UPOV91 (t-2)	0.233	0.173	0.195	0.067	0.013
	(-0.224, 0.972)	(-0.128, 0.670)	(-0.152, 0.467)	(-0.274, 0.379)	(-0.458, 0.295)

Notes: Estimated from a dynamic penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from US (logarithm), for 55 countries over the period 1990-2007. .All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 18, respectively.

4.5.1 Poolability versus heterogeneity

In this sub-section, the rationale and evidence is presented for treating seed exports from the 10 EU countries and from the US as heterogeneous and thus estimated separately, as in our preferred specification. Similarly, the justification for preferring the quantile regression results is also explained, based on heterogeneity of importers. This is done in detail in order to highlight the potential for erroneous inference in simpler model specifications.

This discussion begins by presenting evidence that the three-way model of seed imports as represented by equation (4.5), is misspecified. The results of estimating this model are presented in Table 4.4. Four different estimation techniques are presented with the first two consisting of fixed effects (within) estimates (FE) and random effects (GLS) estimates (RE). For the latter, the time-invariant distance variable has been incuded, and the specific EU exporter effect is shown. For each technique, two specifications are presented, with the first including only the UPOV 1978 variable, and the second one adding the UPOV 1991 variable. All specifications include fertiliser consumption as a second proxy for expenditure on seeds, since for one of the estimations this yielded a coefficient estimate significant at the 10% level. The coefficient estimates are generally plausible, with positive and significant (at 5% significance level or less) values for population (except in the specifications including UPOV 1991), GDP per capita, and negative values for distance from exporter and the importing country's exchange rate. The coefficient on UPOV 1978 is not significantly different from zero in either the FE or RE specifications, but that on UPOV 1991 is significantly negative (at 5% significance level) in both the FE and RE cases. With a value of approximately-0.2, this suggests that UPOV 1991 membership is correlated on average with a 20% decrease in seed imports, which does not amount to an intuitive result.

Although coefficient estimates between the two models are generally similar, a robust Hausman test (as described by Wooldridge 2002, and also Cameron and Trivedi 2010) strongly rejects the hypothesis of a random effects specification due to differences in estimates of specific effects included, as explained in the notes to (Table 4.4). It is apparent though from the adjusted R^2 results that substantial variation is observed between countries. In addition, for many countries, there is no change in the status of the UPOV variable observed in the sample, and thus results from a Hausman-Taylor estimator are also presented in which population and distance were assumed to be the exogenous time-variant variables. These results are generally similar except that UPOV 1978 now has a significant positive coefficient in the fuller model, though the negative effect of UPOV 1991 remains. Under the simpler specification, EU exports are now associated with a significant negative effect on seed imports. The comparison of models HT(1) and HT(2) thus suggests some misspecification, while noting that a test of overidentifying restrictions does not reject these models. For comparison purposes, the Poisson pseudo-maximimum likelihood estimates are also presented in (Table 4.4), presenting some marked differences.[43] For example, the coefficients on population and distance from exporter are no longer significantly different from zero, while the negative coefficient on UPOV 1991 no longer appears.

Given these results, a test of poolability is undertaken to investigate whether the data support a model in which exports from the EU and from the US can be explained by the explanatory variables in a similar way. Following Baltagi (2008), a McElron test is implemented, which strongly rejects the poolability of exporters with test statistics of 51.95 and 72.40, distributed as χ^2 with 7 and 8 degrees of freedom respectively and p-values of less than 0.001. This provides strong evidence to motivate estimating separate models for EU exports and US exports.

Estimation results for EU exports are presented in Table 4.5 and those for the US in Table 4.6. A comparison of the two sets of results indicates that they are indeed quite different. For exports of seeds from the EU, coefficient estimates on importing country's population and GDP per capita are significantly positive in all model specifications, and of a similar magnitude to those in the three-way model. Similarly, the coefficient on distance is significantly negative in all model specifications, though now of a lower magnitude, while that for exchange rate is comparable. The RE models are presented, but a robust Hausman test strongly rejects again the hypothesis that the specific effects are uncorrelated with the error term (see notes to Table 4.5). Given the interest in examining both between and within variation arising from UPOV membership, the Hausman-Taylor (assuming again that population and distance are exogenous time-varying and time-invariant, respectively) and Poisson estimates are of more relevance. For EU seed exports, these two estimators are generally consistent with each other. In three of the four specifications, the estimated coefficient on fertiliser consumption, a proxy for expenditure on seeds in the importing country, is positive at the 5% significance level. Also in three of the four HT and Poisson models, the coefficient estimate for UPOV 1978 membership is now positive at the 5% significance level, and ranging between 0.176 and 0.238.

For US seed exports, there are clear differences in the estimates compared to those for the EU. In general, estimates for the former are much less consistent across different choices of specification. Again, a robust Hausman test strongly rejects a random effects specification, thus directing attention towards the Hausman-Taylor and Poisson estimates.[44] These are also quite different from each other, likely reflecting the higher number of zero observations among US exports (approximately one-tenth), which includes one country, Cote d'Ivoire, that does not import any seed at all from the US in the sample. These observations are ignored by the linear panel methods, but are included in the Poisson model. The results for the Poisson model change substantially when the UPOV 1991 variable is included, which has a significantly negative coefficient, as in the HT model. But now the coefficient estimate on fertiliser consumption

[43] Given the underlying multiplicative model, in both the log-linear specifications and the Poisson specification, the estimated coefficients can be interpreted as semi-elasticities and are thus comparable.

[44] The Poisson estimates are a random effects specification. Essentially identical results were achieved with a fixed effects negative binomial specification (in which time-invariant regressors are identified), also based on bootstrapped standard errors.

decreases in magnitude and the level of significance with which it differs from zero increases to only 10%. The only other coefficient estimate that is significantly different than zero is the one for GDP per capita, with a value similar to that from the HT model.

With more consistency across estimation results, the estimates for the EU exports appear somewhat more robust than those for the US, but we nonetheless conduct poolability tests on both, as detailed in the respective tables. Relatively simple Chow tests on the fixed effects models strongly reject the assumption of poolability, not only for the US exports, but also for the model of those from the EU in both cases. This is confirmed by the McElron test. Given the level of sectoral and product specificity, such a result is perhaps not too surprising (UNCTAD Virtual Institute, 2012) and suggests the application of an approach that incorporates heterogeneity across importing countries. This is the justification for applying quantile regression estimation methods to the model (see (4.10)), including the UPOV 1991 variable. For EU exports these are presented in Table 4.11 and for US exports in Table 4.12, in both cases for five quantiles (τ = 0.1, 0.3, 0.5, 0.7, 0.9) of the dependent variable, seed imports. Thus each column provides a set of estimates, corresponding to each of these quantiles, with $\tau = 0.5$, the middle column consisting essentially of a median regression.[45] It is important to recall that these estimates are for a two-way specification, including both importer country effects and time effects.[46]

Compared to the mean regression results above, there are some clear differences. For the model of seed imports from the EU, there are fewer coefficient estimates that are significantly different from zero at the 5% level. The estimates for the coefficient of GDP per capita is significantly positive at all five quantiles, though with values that are somewhat lower than in the HT or Poisson models. Only two of the coefficient estimates for the exchange rate (at τ = 0.3, 0.5), are significantly below zero and only one for population is significantly above zero ($\tau = 0.3$). Concerning the UPOV variables, UPOV 1978 is significantly positive for τ = 0.7, 0.9, with values in approximately the same range (though a wider confidence interval) than the HT or Poisson models. None of the coefficient estimates for UPOV 1991 is significantly different from zero at the 5% level, which is comparable to the earlier estimates. These estimates would tentatively suggest that UPOV 1978 membership is correlated with approximately a 20-30% higher level of imports of seeds from the EU for countries that are already exporting much more than on average, but that otherwise there is no correlation. But, the model does not appear to be very robust overall, and it will be seen below that these findings change somewhat with a dynamic specification.

For the model of seed imports from the US, there are more similarities between the quantile regression estimates and those of the HT and Poisson models. The coefficient estimate for GDP per capita is of the same order of magnitude (varying between 0.88

[45] Note that time invariant variables, such as distance from exporter, are not identified in the penalized quantile regression for panel data. However, as explained in sec. 4.3, variation both between and within importing countries is incoporated in the estimates, even where the explanatory variable does not exhibit variance over the period of the sample for some of the countries.

[46] A one-way specification of the models in Table 4.11 and Table 4.12 was also estimated which produced fairly similar results (not shown).

at $\tau = 0.5$ to 1.2 at $\tau = 0.1$, as compared to 0.91 in the HT model and 0.89 in the Poisson model). The coefficient estimate for UPOV 1978 remains insignificantly different from zero across all quantiles while that for UPOV 1991 is significantly negative at 5% level across all quantiles at approximately the same value of -0.4 to -0.3 as in the HT and Poisson models. Possible explanations for this result exist[47] but the lack of explanatory power in a number of the principal gravity equation variables suggests first examining omitted, time-variant hetereogeneity through a dynamic specification, which reveals nonstationarity, leading us to the next section. We note though that inference based on these static models alone, even the quantile regression models accounting for heterogeneity, risks finding results that are substantially different from the preferred specifications presented above.

[47] The relatively limited number of countries moving to UPOV 1991 are for the most part found in Europe and there are two reasons why US exports to such countries might actually have declined during the sample period. One is that European economic integration produced some trade diversion. The other is that general European reluctance to adopt genetically modified crops, including a moratorium on their planting during the late 1990's to early 2000's, accounted for a decline in US exports to such markets. Casual inspection of Figure 4.1 to Figure 4.6 suggests some specific countries which might account for such an effect, such as France, Italy, Bulgaria and Hungary in Europe.

Table 4.4: Coefficient estimates for three-way model of seed imports (s.e. in parenthesis)

	FE(1)	FE(2)	RE(1)	RE(2)	HT(1)	HT(2)	P(1)	P(2)
Pop.	1.684†	1.277*	1.686†	1.281*	1.686‡	1.282‡	1.078	1.108
	(0.707)	(0.702)	(0.717)	(0.712)	(0.333)	(0.358)	(0.967)	(0.999)
GDP/capita	1.653‡	1.622‡	1.646‡	1.615‡	1.644‡	1.613‡	1.481‡	1.478‡
	(0.311)	(0.298)	(0.316)	(0.303)	(0.159)	(0.159)	(0.323)	(0.322)
Distance			-1.304‡	-1.305‡	-1.304‡	-1.305‡	-0.379	-0.383
			(0.136)	(0.137)	(0.116)	(0.116)	(0.470)	(0.491)
Crop prod.	0.019	0.011	0.021	0.013	0.021	0.013	-0.153	-0.152
	(0.216)	(0.220)	(0.220)	(0.223)	(0.132)	(0.132)	(0.186)	(0.184)
Fert. cons.	0.099	0.071	0.100	0.072	0.101*	0.072	0.188	0.189
	(0.105)	(0.107)	(0.107)	(0.108)	(0.059)	(0.060)	(0.120)	(0.123)
Exch. rate	-0.217‡	-0.207‡	-0.218‡	-0.208‡	-0.218‡	-0.208‡	-0.226*	-0.226†
	(0.071)	(0.071)	(0.071)	(0.071)	(0.049)	(0.049)	(0.115)	(0.114)
UPOV 1978	0.100	0.135	0.101	0.135	0.101*	0.135†	0.082	0.082
	(0.083)	(0.082)	(0.084)	(0.084)	(0.057)	(0.058)	(0.110)	(0.114)
UPOV 1991		-0.199†		-0.199†		-0.198‡		0.009
		(0.078)		(0.079)		(0.066)		(0.067)
EU exporter			-0.022	-0.018	-0.746‡	-0.290	0.612	0.613
			(0.194)	(0.194)	(0.195)	(0.194)	(0.596)	(0.587)
N	2018	2018	2018	2018	2018	2018	2128	2128
No. groups	110	110	110	110	110	110	112	112
df	41	42	98	99	99	100	26	27
Log-Likelihood							-1,355,656	-1,355,603
F statistic	6.402	6.705			15.321	15.281		
χ^2			.	.	1516.814	1528.055	516.468	508.448
Overall R^2	0.255	0.259						
Adj. overall R^2	0.386	0.421	0.832	0.833				
Adj. betw. R^2	0.435	0.472	0.897	0.897				
Adj. with. R^2	0.255	0.259	0.255	0.259				
σ_u	2.309	1.961	0.794	0.794	0.667	0.667		
σ_e	0.594	0.593	0.594	0.593	0.588	0.586		
ρ	0.938	0.916	0.641	0.642	0.563	0.564		

Notes: Dependent variable is seed imports (log). All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991, and the EU exporter dummy. Columns correspond to different model specifications: FE refers to fixed effects (within) estimates, RE to random effects (GLS) estimates and HT to Hausman-Taylor estimates (for which population and distance are assumed to be exogenous time-varying and time-invariant variables respectively), and P to Poisson random effects maximum likelihood estimates (assuming a Gaussian distribution for α). All models include specific exporter, importer, time and exporter-time effects (only the first is shown in the table). Fixed effects and random effects standard errors estimates are cluster-robust; standard errors for Poisson model are estimated with 200 bootstrap repititions. Significance levels: * for $p < 0.1$; † for $p < 0.05$; ‡ for $p < 0.01$. Sargan-Hansen statistics for a robust Hausman test of random effects assumptions relative to fixed effects: RE(1) 34.03 $p = 0.0004$ for $\chi^2(11)$; RE(2) 35.37 $p = 0.0004$ for $\chi^2(12)$, which differ due primarily to differences in coefficients on specific effects. Sargan-Hansen statistic for test of overidentifying restrictions in HT models: HT(1) 1.507 $p = 0.2196$ for $\chi^2(1)$; HT(2) 0.651 $p = 0.4199$ for $\chi^2(1)$. Estimates for the HT models using an Amemiya-MacCurdy specification (not reported) were almost identical. A McElron test of poolability of FE(1) yields a χ^2 (7) statistic of 51.95 and for FE(2), a χ^2 (8) statistic of 72.40, both with $p < 0.0000$.

Table 4.5: Coefficient estimates for model of seed imports from EU (s.e. in parenthesis)

	FE(1)	FE(2)	RE(1)	RE(2)	HT(1)	HT(2)	P(1)	P(2)
Pop.	1.481†	1.480†	1.020‡	1.015‡	1.082‡	1.091‡	1.178†	1.236†
	(0.613)	(0.612)	(0.292)	(0.299)	(0.209)	(0.209)	(0.507)	(0.514)
GDP/capita	1.708‡	1.727‡	1.30‡	1.304‡	1.834‡	1.860‡	1.358‡	1.239‡
	(0.243)	(0.258)	(0.182)	(0.202)	(0.119)	(0.125)	(0.197)	(0.204)
Distance			-0.801‡	-0.800‡	-0.537†	-0.531†	-0.957‡	-1.007‡
			(0.180)	(0.181)	(0.267)	(0.268)	(0.361)	(0.344)
Crop prod.	-0.139	-0.142	-0.173	-0.171	-0.135	-0.140	-0.129	-0.139
	(0.228)	(0.228)	(0.206)	(0.206)	(0.146)	(0.146)	(0.153)	(0.153)
Fert. cons.	0.156	0.149	0.087	0.092	0.153†	0.142†	0.199*	0.230†
	(0.113)	(0.114)	(0.094)	(0.099)	(0.061)	(0.063)	(0.118)	(0.117)
Exch. rate	-0.266‡	-0.265‡	-0.252‡	-0.252‡	-0.262‡	-0.261‡	-0.231*	-0.229*
	(0.074)	(0.074)	(0.085)	(0.085)	(0.052)	(0.052)	(0.133)	(0.134)
UPOV 1978	0.218*	0.227*	0.348‡	0.341‡	0.224‡	0.238‡	0.199†	0.176*
	(0.122)	(0.116)	(0.113)	(0.110)	(0.062)	(0.065)	(0.091)	(0.093)
UPOV 1991		-0.029		0.019		-0.046		0.057*
		(0.091)		(0.098)		(0.064)		(0.033)
Constant	-20.97†	-20.99†	-2.137	-2.11	-10.83‡	-11.07‡	-11.11	-10.72
	(8.82)	(8.83)	(4.60)	(4.78)	(3.29)	(3.31)	(7.22)	(7.24)
N	1062	1062	1062	1062	1062	1062	1064	1064
No. groups	56	56	56	56	56	56	56	56
df	5	6	7	8	7	8	7	8
Log-Likelihood							-430,704	-427,362
F statistic	22.929	20.153			101.174	88.478		
χ^2			184.522	189.653	708.217	707.825	152.998	152.706
Overall R^2	0.406	0.407						
Adj. overall R^2	0.383	0.385	0.624	0.624				
Adj. betw. R^2	0.392	0.394	0.649	0.649				
Adj. with. R^2	0.406	0.407	0.396	0.396				
σ_u	2.352	2.352	1.147	1.155	2.189	2.191		
σ_e	0.492	0.493	0.492	0.493	0.491	0.491		
ρ	0.958	0.958	0.844	0.846	0.952	0.952		

Notes: Dependent variable is seed imports (log) from 10 EU exporting countries. All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Columns correspond to different model specifications: FE refers to fixed effects (within) estimates, RE to random effects (GLS) estimates and HT to Hausman-Taylor estimates (for which population and distance are assumed to be exogenous time-varying and time-invariant variables respectively), and P to Poisson random effects maximum likelihood estimates (assuming a Gaussian distribution for α). Fixed effects and random effects standard errors estimates are cluster-robust; standard errors for Poisson model are estimated with 200 bootstrap repititions. Significance levels: * for $p < 0.1$; † for $p < 0.05$; ‡ for $p < 0.01$. Sargan-Hansen statistics for a robust Hausman test of random effects assumptions relative to fixed effects: RE(1) 43.58 $p < 0.0000$ for $\chi^2(6)$; RE(2) 39.96 $p < 0.0000$ for $\chi^2(7)$. Sargan-Hansen statistic for test of overidentifying restrictions in HT models: HT(1) 7.547 $p = 0.0060$ for $\chi^2(1)$; HT(2) 7.219 $p = 0.0072$ for $\chi^2(1)$. Estimates for the HT models using an Amemiya-MacCurdy specification (not reported) were almost identical. Test of poolability of FE(1) yields an F(330, 672) statistic of 2.755 with $p < 0.0000$ and for FE(2), 2.175 with df (385, 616) and $p < 0.0000$, which is also confirmed by the McElron test.

Table 4.6: Coefficient estimates for model of seed imports from US (s.e. in parenthesis)

	FE(1)	FE(2)	RE(1)	RE(2)	HT(1)	HT(2)	P(1)	P(2)
Pop.	0.525	0.437	0.393	0.557*	0.804‡	0.877‡	0.577	0.601
	(0.898)	(0.848)	(0.323)	(0.323)	(0.307)	(0.302)	(0.998)	(0.844)
GDP/capita	0.716*	1.023‡	0.801‡	0.956‡	0.648‡	0.905‡	0.489	0.894†
	(0.423)	(0.382)	(0.182)	(0.180)	(0.194)	(0.198)	(0.498)	(0.396)
Distance			-0.953‡	-0.860‡	0.781	0.580	-0.952	-0.748
			(0.251)	(0.235)	(0.765)	(0.752)	(1.087)	(0.979)
Crop prod.	0.218	0.188	0.211	0.176	0.205	0.169	-0.285	-0.419
	(0.387)	(0.376)	(0.297)	(0.295)	(0.225)	(0.220)	(0.346)	(0.318)
Fert. cons.	0.178	0.042	0.173	0.044	0.191*	0.067	0.528†	0.359*
	(0.194)	(0.191)	(0.158)	(0.157)	(0.101)	(0.103)	(0.256)	(0.210)
Exch. rate	-0.131	-0.124	-0.110	-0.098	-0.125	-0.114	-0.245	-0.191
	(0.130)	(0.126)	(0.118)	(0.117)	(0.088)	(0.086)	(0.227)	(0.204)
UPOV 1978	-0.100	0.036	-0.088	0.058	-0.107	0.019	0.075	0.095
	(0.131)	(0.131)	(0.130)	(0.126)	(0.093)	(0.095)	(0.122)	(0.144)
UPOV 1991		-0.442‡		-0.446‡		-0.424‡		-0.339‡
		(0.127)		(0.126)		(0.096)		(0.101)
Constant	-5.403	-4.921	4.601	1.257	-16.53*	-16.54*	7.392	5.653
	(9.378)	(9.201)	(3.915)	(3.876)	(9.179)	(9.004)	(12.007)	(10.079)
N	956	956	956	956	956	956	1045	1045
No. groups	54	54	54	54	54	54	55	55
df	5	6	7	8	7	8	7	8
Log-Likelihood							-861,556	-807,579
F statistic	4.008	4.962			15.384	16.424		
χ^2			98.900	116.161	107.688	131.393	31.541	47.423
Overall R^2	0.064	0.086						
Adj. overall R^2	0.433	0.485	0.524	0.539				
Adj. between R^2	0.521	0.586	0.623	0.635				
Adj. within R^2	0.064	0.086	0.063	0.085				
σ_u	1.454	1.354	1.286	1.288	1.362	1.349		
σ_e	0.706	0.698	0.706	0.698	0.703	0.695		
ρ	0.809	0.790	0.769	0.773	0.789	0.790		

Notes: Dependent variable is seed imports from US (log). All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Columns correspond to different model specifications: FE refers to fixed effects (within) estimates, RE to random effects (GLS) estimates and HT to Hausman-Taylor estimates (for which population and distance are assumed to be exogenous time-varying and time-invariant variables respectively), and P to Poisson random effects maximum likelihood estimates (assuming a Gaussian distribution for α). Fixed effects and random effects standard errors estimates are cluster-robust; standard errors for Poisson model are estimated with 200 bootstrap repititions. Significance levels: * for $p < 0.1$; † for $p < 0.05$; ‡ for $p < 0.01$. Sargan-Hansen statistics for a robust Hausman test of random effects assumptions relative to fixed effects: RE(1) 8.201 $p < 0.2237$ for $\chi^2(6)$; RE(2) 9.922 $p < 0.1930$ for $\chi^2(7)$. Sargan-Hansen statistic for test of overidentifying restrictions in HT models: HT(1) 0.914 $p = 0.3390$ for $\chi^2(1)$; HT(2) 2.375 $p = 0.1233$ for $\chi^2(1)$. Test of poolability of FE(1) yields an F(330, 672) statistic of 1.5778 with $p < 0.0000$ and for FE(2), 1.211 with df (385, 616) and $p < 0.0179$, which is also confirmed by the McElron test.

4.5.2 Nonstationarity

This sub-section provides evidence to justify the autoregressive distributed lag specification presented as the preferred results. As described in the previous sub-section, the lack of coefficient estimates that are significantly different from zero, even using relatively robust quantile regression techniques, and the general imprecision of those estimates which are significantly different from zero, suggests possible omitted variables or some other form of misspecification. Time-invariant omitted variables are partly accounted for by the country-specific effects. In order to make an attempt to capture the effects of unobserved time-varying heterogeneity, a dynamic specification of the quantile regression model with fixed effects (4.13) is estimated, beginning with one with the inclusion of a one-period lag on seed imports.

Coefficient estimates of these simple dynamic models are presented in Table 4.9 and Table 4.10 respectively and the results are quite different from those of the static models.[48] The most important aspect of the results though concerns the nature of dynamics, and the apparently high degree of state dependence. The estimated coefficient on lagged value of seed imports from the EU is signficant and very close to one in all quantiles, and the 95% confidence interval even exceeds one in the lowest quantile, suggesting nonstationarity. For US exports, there is evidence of at least a certain degree of state dependence. The estimated coefficient on lagged seed imports is significantly positive and decreasing slightly in the higher quantiles. The value of this coefficient, ranging from 0.55 to 0.83, is markedly less than that of the EU, but consistent with the findings of Yang and Woo (2006) who had a coefficient estimate of 0.64 in their dynamic linear panel data model with random effects using GLS.

Given these results, a number of panel unit root tests were therefore implemented. The Levin-Lin-Chu test of the null hypothesis of nonstationarity for all importing countries versus the alternative hypothesis of stationarity is strongly rejected for both samples (test statistics of -5.836 for EU exports and -10.873 for US exports, both with p-values < 0.001). This test assumes though homogeneity in the coefficient on lagged imports across all countries. The Im, Pesaran and Shin test of the null hypothesis of nonstationarity for all importing countries versus the alternative hypothesis of stationarity for at least some of the countries is also strongly rejected for both sets

[48]Considering the EU exports, the estimated coefficients on GDP per capita in the dynamic model are significantly greater than zero for four of the five quantiles, but of a much smaller magnitude than in the static model, and none of the estimated coefficients on population or the exchange rate is significantly different than zero. Only one of the estimated coefficients on UPOV 1978 is significantly positive, now for $\tau = 0.1$, as compared to the static model where this was the case for $\tau = 0.7$, 0.9. And whereas none of the coefficient estimates were significantly different from zero for UPOV 1991 in the static model, those for $\tau = 0.5$, 0.7 and 0.9, are significantly positive in the dynamic model (and increasing over the quantiles). In some contrast to the EU, there are fewer differences between the estimation results for the dynamic model for the US relative to the static specification. The estimated coefficients on GDP per capita are significantly positive in four out of the five quantiles, compared to all five quantiles in the static model, though again of a lower value. With respect to UPOV variables, the estimated effect of 1978 membership remains insignificant across all quantiles, while that of 1991 membership is also significantly negative, though for only four of the quantiles. This value is also by approximately one-third to one-half, taking into account not only the point estimates but also the 95% confidence intervals.

of seed exports (test statistics of -2.834 for EU exports with p-value = 0.0046; and -10.591 for US exports, with p-value < 0.001).[49] Given the heterogeneity that is clearly evident in the data with some series likely being subject to nonstationarity, the Hadri test of the null hypothesis of no unit roots versus the alternative hypothesis of at least one series having a unit root is also strongly rejected for both series (test statistics of 47.85 for EU exports and 23.10 for US exports, both with p-values < 0.001). This last test thus provides strong evidence that at least some of the series in each sample exhibit a unit root. The estimates of the simple dynamic models could therefore be inconsistent.

Proceeding in a systematic fashion, the next issue concerns whether seed imports are cointegrated with other variables, which would then lead to a choice of panel vector autoregressions (although the number of time periods in the sample is clearly limited for such a model). A number of panel cointegration tests, proposed by Westerlund (2007) are implemented allowing for different lag structures between seed imports and each of the continuous explanatory variables.[50] Given the apparent heterogeneity in the samples, attention concentrates primarily on the results of Westerlund's two group mean tests, which test the null hypothesis of no cointegration against the alternative hypothesis of there being cointegration in at least one of the groups.[51] The results of these tests are generally inconclusive; for each set of options chosen, one of the group mean tests often rejects the null hypothesis of no cointegration (at 99.99% significance level) while the other test never does.[52] On balance, these results provide incomplete guidance as to how to proceed. The presence of cointegration would imply the need to await additional data for the application of a vector error-correction model (VECM) as the current length of panel is insufficient for such techniques. On the other hand, the absence of cointegration would permit the application of a simpler autoregressive distributed lag model, including additional lagged explanatory variables, which would still yield consistent (as opposed to spurious) estimates in a mean regression context (Verbeek, 2004). We chose to apply this latter strategy to the dataset for pragmatic reasons (the former strategy is not currently feasible given data limitations[53]). Perhaps the quantile regression framework is more robust than OLS to this potential misspecification, but this issue does not appear to have been

[49] In their analysis of US seed exports, Yang and Woo (2006) also reject the null hypothesis of nonstationarity for all importing countries, based on the Im, Pesaran and Shin test.

[50] Using the Stata command `xtwest`, as described by Persyn and Westerlund (2008), and following their suggestions to limit lags and leads with a fairly short panel as in our case. We first conduct Pesaran's (2004) test for cross-section dependence and cannot reject the null hypothesis of independence in either sample (i.e. EU exports or US exports).

[51] In contrast, Westerlund's two 'panel' tests assume homogeneity across countries in the error correction parameter.

[52] Specifically, following the terminology of Persyn and Westerlund (2008), the G_α test often rejects the null hypothesis of cointegration, while the G_t test never does.

[53] The strategy would have to be one of first testing for unit roots and structural breaks in the panel, as has been demonstrated by Carrion-i-Silvestre *et al.* (2005), and see also the overview by Breitung and Pesaran (2008). This would entail testing for structural breaks, using the testing framework of Bai and Perron (1998; 2003), in each of the series separately as a first step. These tests will have relatively limited power though with maximum series length of 19 . We therefore leave such an approach for future work when more additional data allows the analysis of a longer panel.

examined systematically. Thus, it is important to bear this combination of caveats in mind in interpreting the preferred results presented above.

4.6 Conclusions

Our analysis has further contributed to the efforts of Yang and Woo (2006) to assess the effects of IPRs on seed trade by adding the major European exporters to their analysis of US exports, and also by adding additional years of data. Similar to those authors, we also fail to find any significant correlation between UPOV membership and either US or EU seed exports to importing countries. Aside from the additional data, which further generalizes Yang and Woo's results, we have differentiated between the two versions of the UPOV Treaty still in effect and the corresponding scope of protection.

To the extent that our results are robust, they suggest two explanations. One is that other factors influencing the international trade in seeds are more important than PBRs. Some have been included in this analysis and the extent to which others have not been included, such as tariffs[54] and other specific regulations affecting the sector, the analysis is then misspecified. A more complete specification of this gravity equation could therefore still reveal a positive correlation between UPOV membership and seed imports, though of a smaller magnitude than other factors. The second explanation for the lack of an effect of PBRs on trade is that PBRs implemented in many countries have generally not been perceived as being effective by seed companies. In this regard, the analysis is lacking a variable that incorporates the effectiveness or enforceability of PBRs and this could be an area for future research on this topic. Based on other findings (Leger, 2005; Tripp, Louwaars and Eaton, 2007), this explanation seems quite plausible. If it is the case that this form of IPR protection exists more on paper than in practice, than it becomes relevant from a policy perspective to understand the reasons for this.

From a methodological point of view, we applied quantile regression techniques, exploiting developments in this area in recent years, in particular the fixed effects quantile regression proposed by Koenker (2004; 2005), and recent extensions for dynamic models by Galvao (2011) and Galvao and Montes-Rojas (2010). This was based on statistical evidence of heterogeneity among importing countries, and we also had evidence of heterogeneity among the two sets of exporters considered. Growth in the range of models for which quantile regression methods are being developed parallels the growing interest in incorporating heterogeneity in econometric modelling, which includes other conditional mean approaches such as random coefficients, random parameters, and semi-parametric models.

[54]Note that we did examine the World Bank's World Integrated Trade Solution database for data on tariffs applicable to the seed sector (`http://wits.worldbank.org/wits/`). In general, these tariffs have not varied much for individual countries over the course of our study and so the effects can generally not be identified in a fixed effects framework.

Panel unit root tests indicate that at least some of the importing countries series are nonstationary. We are though unable to find much evidence of a cointegrating relationship between seed imports and other explanatory variables in the gravity model. Our preferred specifications have therefore an autoregressive distributed lag structure, incorporating two lags, which reveals very little explanatory power among the gravity equation variables. Thus, it is a preferred specification in terms of the line of investigation suggested by the gravity model and previous literature in this area, but it is clearly far from satisfactory in terms of explanatory power.

We conclude from this analysis thus that the dynamic gravity model fails to explain seed trade in an adequate manner. In a static version, it may perform sufficiently well in explaining the overall pattern of aggregate trade among countries as this is related to factors such as GDP, population and distance between exporters and importers. But when interest focuses on the effects of a specific policy variable, or aspect of the institutional environment - in our case IPRs - then the dynamic considerations need to be taken into account, and the neglect of fixed effects seems hard to justify. The new developments in panel vector autoregression (VAR) models, including the analysis of stationarity and structural breaks (as mentioned above), may offer a more appropriate framework for empirical analysis of these types of issues. Such approaches do however require somewhat longer panels in order for hypothesis-testing to have useful power. In addition, our results indicated the need to take account of structural differences between importing countries and new estimators for heterogeneous panels may offer an alternative approach to the quantile regression framework (Pesaran, 2006; Eberhardt, 2012).

It is also relevant to examine specific sub-groups of crops, such as grains and oilseeds, seed potatoes, fruit and vegetables, ornamentals, as both protection measures and incentives might vary for vegetatively-propagated species (e.g. potatoes) or open-pollinated species (e.g. wheat). The results indicate that more crop-specific explanatory variables, as well as a different structural model, would be necessary for such a purpose. At the level of individual crops, it is possible to decompose value flows into quantities and prices, which is not possible when aggregating across diverse crop species. Note though that the approach taken here is still of importance from a policy perspective. The UPOV Convention, particularly its 1991 Act, requires countries to offer PBR protection for all crop species. It is then relevant to investigate whether impacts can be observed at an aggregate level, in the current context in terms of trade flows.

Aside from IPRs, our analysis suggests that other factors affecting trade costs may play a more important role in influencing international trade in agricultural seeds, and these could be further investigated. It also seems relevant to conduct more research on the relative effectiveness of PBR systems.

Effective and well-designed intellectual property rights are expected, in theory, to contribute to technology transfer by trade, licensing or foreign direct investment. In this chapter, we have examined only the effect on trade in the specific sector of agricultural seeds. While cross-border, arms-length licensing of seed production is not generally observed in the seed sector, foreign direct investment is a more common channel, one that provides plant breeding companies with more options to control the use of their seeds and possible appropriation by others. In finding no evidence of an effect of PBRs, as the principal IPR in the agricultural seed sector, on trade, our analysis suggests that research examine the possible effects on investment, although data on such flows are not regularly collected nor available (neither domestically nor internationally). Indeed, the availability of data on investment, both foreign and domestic, may help assess the relative plausibility of the alternative explanations for the current results reported in this chapter.

4.7 Annex

4.7.1 Countries sorted by quintiles of seed imports

Table 4.7: Countries sorted by quintiles of annual seed imports from 10 EU countries over 1989-2007 (cutoff values in US$ 000)

0.2	0.4	0.6	0.8	1.0
($M_{it} \leq 448$)	($448 < M_{it} \leq 1898$)	($1898 < M_{it} \leq 6180$)	($6180 < M_{it} \leq 26,316$)	($26,316 < M_{it}$)
Albania	Albania	Albania		
			Algeria	Algeria
	Argentina	Argentina	Argentina	
		Australia	Australia	
			Austria	Austria
Bangladesh	Bangladesh	Bangladesh		
		Brazil	Brazil	
Bulgaria	Bulgaria	Bulgaria	Bulgaria	
Cameroon	Cameroon			
		Canada	Canada	
	Chile	Chile		
China	China	China	China	
Colombia	Colombia			
Costa Rica	Costa Rica			
Cote d'Ivoire	Cote d'Ivoire			
			Denmark	Denmark
Ecuador	Ecuador			
		Egypt	Egypt	Egypt
El Salvador				
			Finland	
				France
				Germany
			Hungary	Hungary
	India	India		
Indonesia	Indonesia	Indonesia		
	Iran	Iran	Iran	
				Italy
			Japan	
		Jordan	Jordan	
	Kenya	Kenya		
Malaysia				
Mexico	Mexico	Mexico	Mexico	
			Morocco	Morocco
				Netherlands

0.2	0.4	0.6	0.8	1.0
New Zealand	New Zealand	New Zealand		
Nigeria	Nigeria			
		Norway	Norway	
	Pakistan	Pakistan		
Peru	Peru			
Philippines	Philippines			
				Portugal
	Romania	Romania	Romania	
	Senegal	Senegal		
	South Africa	South Africa	South Africa	South Africa
	South Korea	South Korea		
				Spain
	Sri Lanka	Sri Lanka		
			Sweden	
Thailand	Thailand	Thailand		
		Tunisia	Tunisia	
			Turkey	Turkey
				UK
Uruguay	Uruguay			
			US	US
Venezuela	Venezuela	Venezuela		
Zambia	Zambia			

Table 4.8: Countries sorted by quintiles of annual seed imports from the US over 1989-2007 (cutoff values in US$ 000)

0.2	0.4	0.6	0.8	1.0
$(M_{it} \leq 257)$	$(257 < M_{it} \leq 1666)$	$(1666 < M_{it} \leq 4017)$	$(4017 < M_{it} \leq 11,937)$	$(11,937 < M_{it})$
Albania	Albania			
	Algeria	Algeria	Algeria	
			Argentina	Argentina
			Australia	Australia
	Austria	Austria	Austria	Austria
Bangladesh	Bangladesh			
		Brazil	Brazil	
Bulgaria	Bulgaria			
Cameroon				
				Canada
			Chile	Chile
	China	China	China	China
		Colombia	Colombia	

0.2	0.4	0.6	0.8	1.0
	Costa Rica	Costa Rica	Costa Rica	
Cote d'Ivoire				
	Denmark	Denmark	Denmark	
	Ecuador	Ecuador	Ecuador	
		Egypt	Egypt	Egypt
	El Salvador	El Salvador		
Finland	Finland			
				France
			Germany	Germany
	Hungary	Hungary	Hungary	
	India	India	India	
Indonesia	Indonesia			
Iran	Iran	Iran		
				Italy
				Japan
	Jordan	Jordan		
Kenya	Kenya	Kenya		
Malaysia	Malaysia			
				Mexico
	Morocco	Morocco		
				Netherlands
	New Zealand	New Zealand	New Zealand	
Nigeria	Nigeria	Nigeria		
Norway	Norway			
	Pakistan	Pakistan	Pakistan	Pakistan
	Peru	Peru	Peru	
	Philippines	Philippines	Philippines	
		Portugal	Portugal	
Romania	Romania	Romania	Romania	Romania
Senegal	Senegal			
		South Africa	South Africa	South Africa
			South Korea	South Korea
				Spain
	Sri Lanka			
	Sweden	Sweden	Sweden	
	Thailand	Thailand	Thailand	
Tunisia	Tunisia			
		Turkey	Turkey	Turkey
			UK	UK
	Uruguay	Uruguay		
		Venezuela	Venezuela	Venezuela
Zambia	Zambia	Zambia		

4.7.2 Additional results

4.7.2.1 Quantile regression estimates of simple dynamic model

Table 4.9: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way dynamic model of seed imports from EU

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-2.658†	-0.841	-0.873	-0.371	0.731
	(-5.165, -1.032)	(-2.937, 0.087)	(-2.795, 0.54)	(-3.082, 1.484)	(-2.822, 1.999)
Seed imports (t-1)	1.025†	0.960†	0.945†	0.887†	0.889†
	(0.956, 1.048)	(0.912, 0.985)	(0.876, 0.974)	(0.815, 0.94)	(0.82, 0.93)
Population	0.013	-0.012	0.026	0.172	0.072
	(-0.101, 0.16)	(-0.086, 0.165)	(-0.095, 0.161)	(-0.035, 0.265)	(-0.136, 0.286)
GDP/capita	0.113†	0.078†	0.067†	0.091†	-0.002
	(0.035, 0.213)	(0.047, 0.149)	(0.02, 0.143)	(0.013, 0.178)	(-0.075, 0.12)
Crop prod.	0.056	0.026	0.017	-0.095	-0.042
	(-0.036, 0.131)	(-0.097, 0.098)	(-0.098, 0.111)	(-0.173, 0.127)	(-0.167, 0.113)
Fert. cons.	-0.079	0.006	-0.025	-0.023	-0.002
	(-0.149, 0.016)	(-0.092, 0.05)	(-0.1, 0.037)	(-0.138, 0.065)	(-0.149, 0.107)
Exch. Rate	0.003	-0.026	0.006	-0.010	0.073
	(-0.231, 0.234)	(-0.124, 0.079)	(-0.073, 0.064)	(-0.087, 0.07)	(-0.088, 0.459)
UPOV78	0.097†	0.011	-0.007	-0.021	-0.093
	(0.016, 0.243)	(-0.040, 0.106)	(-0.059, 0.063)	(-0.149, 0.078)	(-0.292, 0.071)
UPOV91	0.019	0.056	0.049†	0.067†	0.092†
	(-0.034, 0.099)	(-0.009, 0.094)	(0.007, 0.088)	(0.002, 0.127)	(0.003, 0.179)

Notes: Estimated from a dynamic penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from EU exporting countries (logarithm), for 56 countries over the period 1989-2007. .All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 2 and 12, respectively.

Table 4.10: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way dynamic model of seed imports from US

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-6.916†	-5.255†	-3.005	-4.084	-3.091
	(-15.099, -0.597)	(-8.876, -1.271)	(-6.875, 0.22)	(-6.225, 1.063)	(-8.37, 2.536)
Seed imports (t-1)	0.813†	0.728†	0.826†	0.667†	0.546†
	(0.386, 0.886)	(0.504, 0.909)	(0.501, 0.938)	(0.506, 0.787)	(0.460, 0.796)
Population	0.138	0.142	0.047	0.135	0.142
	(-0.340, 1.126)	(-0.117, 0.623)	(-0.132, 0.545)	(-0.096, 0.680)	(-0.277, 0.487)
GDP/capita	0.341†	0.329†	0.170†	0.243†	0.135
	(0.178, 1.158)	(0.138, 0.696)	(0.048, 0.572)	(0.079, 0.581)	(-0.048, 0.476)
Crop prod.	0.109	0.089	0.086	0.125	0.248
	(-1.081, 0.487)	(-0.377, 0.336)	(-0.367, 0.263)	(-0.395, 0.293)	(-0.291, 0.575)
Fert. cons.	-0.011	0.002	-0.031	-0.091	-0.190
	(-0.099, 0.677)	(-0.049, 0.288)	(-0.052, 0.306)	(-0.088, 0.179)	(-0.344, 0.212)
Exch. Rate	0.016	-0.005	0.086	0.070	-0.141
	(-0.005, 0.440)	(-0.084, 0.255)	(-0.087, 0.260)	(-0.197, 0.091)	(-0.447, 0.436)
UPOV78	0.264	0.060	0.032	0.116	0.277
	(-0.288, 0.584)	(-0.116, 0.164)	(-0.058, 0.126)	(-0.107, 0.146)	(-0.148, 0.213)
UPOV91	-0.106†	-0.179†	-0.100†	-0.150†	-0.167
	(-0.455, -0.052)	(-0.245, -0.035)	(-0.234, -0.011)	(-0.306, -0.034)	(-0.402, 0.041)

Notes: Estimated from a dynamic penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from US (logarithm), for 55 countries over the period 1989-2007. .All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 2 and 14, respectively.

4.7.2.2 Quantile regression estimates of static model

Table 4.11: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way model of seed imports from EU

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-4.010	-12.685†	-15.818†	-11.117†	-0.140
	(-22.344, 4.035)	(-24.200, -0.760)	(-23.223, -2.471)	(-20.858, -0.170)	(-13.058, 7.503)
Population	0.608	0.781†	0.713	0.536	0.422
	(-0.166, 1.524)	(0.102, 1.346)	(-0.117, 1.236)	(-0.300, 1.129)	(-0.335, 1.027)
GDP/capita	1.106†	1.360†	1.259†	1.059†	0.743†
	(0.779, 1.655)	(0.935, 1.782)	(0.851, 1.624)	(0.701, 1.556)	(0.468, 1.332)
Crop prod.	-0.321	-0.138	0.097	0.087	-0.204
	(-0.981, 0.568)	(-0.549, 0.451)	(-0.328, 0.531)	(-0.379, 0.458)	(-0.620, 0.375)
Fert. cons.	0.127	0.110	0.087	0.162	0.183
	(-0.234, 0.353)	(-0.075, 0.313)	(-0.057, 0.351)	(-0.038, 0.391)	(-0.154, 0.439)
Exch. Rate	-0.385	-0.358†	-0.293†	-0.314	-0.318
	(-0.636, 0.076)	(-0.601, -0.083)	(-0.503, -0.016)	(-0.420, -0.030)	(-0.505, 0.029)
UPOV78	0.178	0.232	0.169	0.219†	0.342†
	(-0.126, 0.631)	(-0.092, 0.499)	(-0.024, 0.517)	(0.020, 0.465)	(0.035, 0.651)
UPOV91	0.314	0.110	0.076	0.074	0.087
	(-0.003, 0.492)	(-0.121, 0.288)	(-0.101, 0.225)	(-0.097, 0.231)	(-0.064, 0.271)

Notes: Estimated from a penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from EU exporting countries (logarithm), for 56 countries over the period 1989-2007.All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 16, respectively.

Table 4.12: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way model of seed imports from US

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-11.965†	-12.297†	-11.525†	-9.811†	-10.281†
	(-21.950, -4.145)	(-19.125, -4.883)	(-19.412, -4.565)	(-15.777, -3.339)	(-18.787, -2.166)
Population	0.409†	0.425	0.449	0.489	0.387
	(-0.109, 1.284)	(-0.096, 0.88)	(-0.074, 0.91)	(-0.219, 0.955)	(-0.328, 1.251)
GDP/capita	1.122†	0.935†	0.875†	0.900†	0.957†
	(0.707, 1.666)	(0.588, 1.431)	(0.604, 1.292)	(0.567, 1.198)	(0.497, 1.324)
Crop prod.	0.139	0.219	0.186	0.071	0.185
	(-0.733, 0.682)	(-0.365, 0.704)	(-0.348, 0.685)	(-0.392, 0.677)	(-0.465, 0.851)
Fert. cons.	0.037	0.051	0.072	0.126	0.062
	(-0.159, 0.516)	(-0.170, 0.394)	(-0.140, 0.426)	(-0.136, 0.370)	(-0.323, 0.419)
Exch. Rate	-0.050	-0.044	-0.017	-0.036	-0.022
	(-0.287, 0.131)	(-0.296, 0.113)	(-0.389, 0.546)	(-0.349, 0.293)	(-0.252, 0.361)
UPOV78	0.096	0.049	0.078	0.052	0.039
	(-0.183, 0.483)	(-0.158, 0.365)	(-0.192, 0.264)	(-0.093, 0.218)	(-0.099, 0.336)
UPOV91	-0.434†	-0.383†	-0.345†	-0.327†	-0.365†
	(-0.740, -0.246)	(-0.584, -0.227)	(-0.572, -0.220)	(-0.498, -0.160)	(-0.659, -0.131)

Notes: Estimated from a penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from the US (logarithm), for 55 countries over the period 1989-2007. All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 17, respectively.

4.7.2.3 Quantile regression estimates for larger dataset

Table 4.13: Quantile regression coefficient estimates and 95% confidence intervals by quantile for dynamic two-way simplified model of seed imports from EU

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-2.775†	-1.429†	-1.283†	-0.537	0.350
	(-4.522, -0.224)	(-3.213, -0.021)	(-3.530, -0.149)	(-3.208, 0.162)	(-1.728, 1.462)
Seed imports (t-1)	0.611†	0.560†	0.547†	0.486†	0.477†
	(0.530, 0.736)	(0.491, 0.662)	(0.475, 0.602)	(0.413, 0.571)	(0.355, 0.602)
Seed imports (t-2)	0.348†	0.350†	0.331†	0.359†	0.360†
	(0.238, 0.415)	(0.246, 0.415)	(0.226, 0.391)	(0.263, 0.438)	(0.247, 0.458)
Population	0.072	0.059	0.068	0.050	0.117
	(-0.055, 0.266)	(-0.148, 0.217)	(-0.145, 0.224)	(-0.075, 0.204)	(-0.054, 0.254)
GDP/capita	0.529	0.132	-0.012	0.123	-0.233
	(-1.072, 1.394)	(-0.227, 0.746)	(-0.620, 0.713)	(-0.749, 1.343)	(-0.944, 0.800)
GDP/capita (t-1)	0.406	0.848	0.381	0.009	-0.333
	(-0.951, 2.736)	(-0.231, 1.594)	(-0.721, 1.675)	(-1.487, 1.135)	(-1.634, 1.175)
GDP/capita (t-2)	-0.782	-0.868	-0.249	-0.035	0.640
	(-2.013, 0.056)	(-1.584, 0.125)	(-1.219, 0.432)	(-0.719, 0.644)	(-0.434, 1.213)
Ag. GDP	0.016	0.005	0.011	0.018	-0.042
	(-0.173, 0.131)	(-0.145, 0.218)	(-0.130, 0.227)	(-0.106, 0.182)	(-0.135, 0.118)
Exch. Rate	-0.112	-0.172	-0.114	-0.097	-0.163
	(-0.770, 0.204)	(-0.46, 0.047)	(-0.366, 0.053)	(-0.302, 0.051)	(-0.410, 0.116)
Exch. Rate (t-1)	-0.119	0.091	0.057	-0.030	-0.048
	(-0.621, 0.777)	(-0.261, 0.306)	(-0.176, 0.321)	(-0.170, 0.365)	(-0.350, 0.612)
Exch. Rate (t-2)	0.209	0.089	0.046	0.118	0.162
	(-0.206, 0.561)	(-0.080, 0.342)	(-0.108, 0.240)	(-0.144, 0.174)	(-0.343, 0.356)
UPOV78	0.126	0.111	0.036	0.001	-0.036
	(-0.077, 0.393)	(-0.131, 0.214)	(-0.166, 0.128)	(-0.113, 0.149)	(-0.165, 0.267)
UPOV78 (t-1)	-0.298	-0.155	-0.073	-0.066	-0.042
	(-0.771, 0.154)	(-0.303, 0.134)	(-0.246, 0.138)	(-0.282, 0.224)	(-0.304, 0.138)
UPOV78 (t-2)	0.217	0.144	0.086	0.098	0.097
	(-0.134, 0.671)	(-0.021, 0.294)	(-0.016, 0.248)	(-0.131, 0.26)	(-0.056, 0.231)
UPOV91	0.079	0.052	0.076	0.095	0.054
	(-0.069, 0.261)	(-0.093, 0.161)	(-0.029, 0.177)	(-0.001, 0.199)	(-0.046, 0.156)
UPOV91 (t-1)	-0.007	0.006	-0.053	-0.011	0.000
	(-0.226, 0.171)	(-0.135, 0.178)	(-0.140, 0.101)	(-0.179, 0.076)	(-0.078, 0.185)
UPOV91 (t-2)	-0.074	-0.086†	-0.043	-0.064	-0.042
	(-0.145, 0.073)	(-0.172, -0.006)	(-0.168, 0.019)	(-0.146, 0.052)	(-0.208, 0.024)

Notes: Estimated from a dynamic penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from EU exporting countries (logarithm), for 71 countries over the period 1989-2007. All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 11.6, respectively.

Table 4.14: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way simplified model of seed imports from EU

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-13.215†	-15.608†	-16.592†	-14.592†	-7.952†
	(-23.602, -4.310)	(-23.979, -7.064)	(-23.990, -8.628)	(-22.116, -6.743)	(-17.353, -2.566)
Population	1.178†	1.040†	0.902†	0.882†	0.739†
	(0.175, 1.731)	(0.401, 1.51)	(0.348, 1.402)	(0.435, 1.378)	(0.377, 1.251)
GDP/capita	1.495†	1.336†	1.149†	1.16†	1.02†
	(0.928, 1.787)	(1.032, 1.679)	(0.890, 1.469)	(0.868, 1.419)	(0.659, 1.317)
Ag. GDP	-0.461	-0.196	0.032	-0.064	-0.194
	(-0.991, 0.457)	(-0.557, 0.346)	(-0.438, 0.422)	(-0.436, 0.319)	(-0.539, 0.175)
Exch. Rate	-0.291	-0.187	-0.169	-0.05	-0.075†
	(-0.603, 0.081)	(-0.555, 0.061)	(-0.436, 0.028)	(-0.445, 0.015)	(-0.515, -0.013)
UPOV78	0.143	0.175	0.221	0.179	0.269†
	(-0.172, 0.508)	(-0.101, 0.426)	(-0.013, 0.466)	(-0.001, 0.468)	(0.051, 0.619)
UPOV91	0.215†	0.086	0.086	0.069	0.042
	(0.031, 0.447)	(-0.116, 0.233)	(-0.106, 0.192)	(-0.096, 0.192)	(-0.073, 0.223)

Notes: Estimated from a penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from EU exporting countries (logarithm), for 71 countries over the period 1989-2007. All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 13, respectively.

Table 4.15: Quantile regression coefficient estimates and 95% confidence intervals by quantile for two-way simplified model of seed imports from US

Variable	0.1	0.3	0.5	0.7	0.9
Intercept	-17.641†	-14.202†	-13.128†	-11.767†	-11.428†
	(-31.020, -11.873)	(-23.700, -9.03)	(-22.125, -8.364)	(-20.642, -8.071)	(-18.209, -6.264)
Population	0.265	0.363	0.497†	0.708†	0.801†
	(-0.439, 1.042)	(-0.141, 0.921)	(0.196, 1.036)	(0.192, 1.035)	(0.062, 1.410)
GDP/capita	1.149†	1.041†	1.006†	1.026†	1.110†
	(0.703, 1.811)	(0.693, 1.583)	(0.732, 1.568)	(0.728, 1.506)	(0.706, 1.499)
Ag. GDP	0.512	0.331	0.189	-0.030	-0.110
	(-0.150, 1.312)	(-0.068, 0.827)	(-0.197, 0.482)	(-0.254, 0.470)	(-0.623, 0.511)
Exch. Rate	-0.163	-0.110	-0.031	-0.017	-0.062
	(-0.325, 0.104)	(-0.246, 0.048)	(-0.193, 0.137)	(-0.267, 0.060)	(-0.226, 0.254)
UPOV78	0.084	0.052	0.057	0.046	0.083
	(-0.132, 0.442)	(-0.136, 0.341)	(-0.151, 0.221)	(-0.108, 0.183)	(-0.081, 0.320)
UPOV91	-0.473†	-0.424†	-0.376†	-0.355†	-0.409†
	(-0.768, -0.334)	(-0.598, -0.273)	(-0.601, -0.247)	(-0.549, -0.225)	(-0.740, -0.189)

Notes: Estimated from a penalized fixed effects quantile regression, with penalized country-specific and time-specific effects. Dependent variable is annual seed imports from the US (logarithm), for 70 countries over the period 1989-2007. All explanatory variables are included as logarithms, except UPOV 1978 and UPOV 1991. Confidence intervals, presented in parentheses, are estimated using 400 panel bootstrap replications, and coefficient estimates that are significantly different from zero are indicated with '†' to aid in interpretation. The penalty parameters were selected (with intervals of 0.2) to optimize the information criteria proposed by Koenker (2010) using a median regression ($\tau = 0.5$) leading to values for the country-specific and time-specific effects of 1 and 18, respectively.

4.7.3 Seed imports disaggregated by crop

Figure 4.7: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 1 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

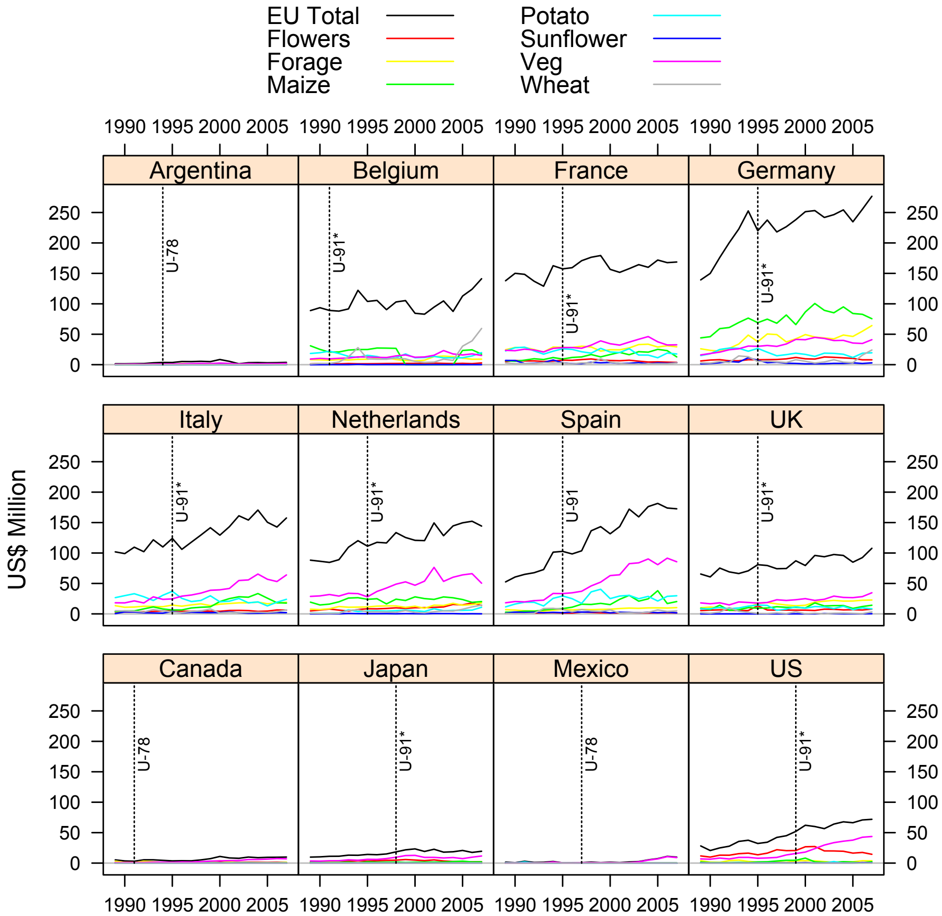


Figure 4.8: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 1 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

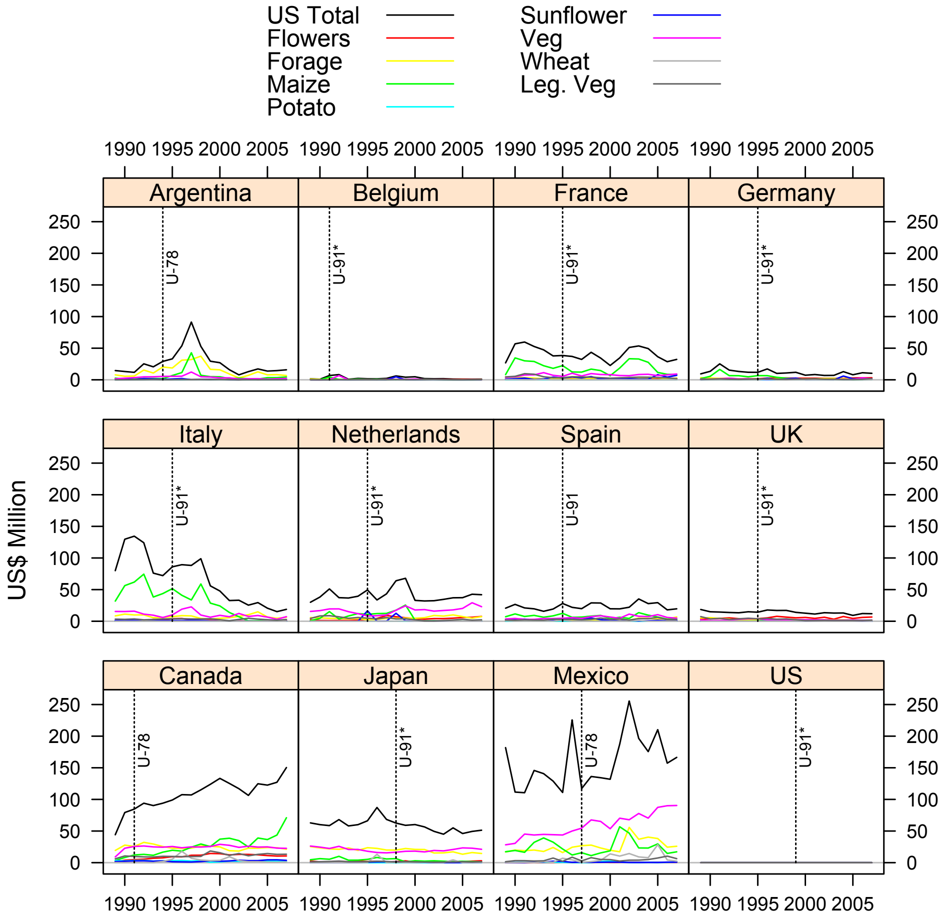


Figure 4.9: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 2 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

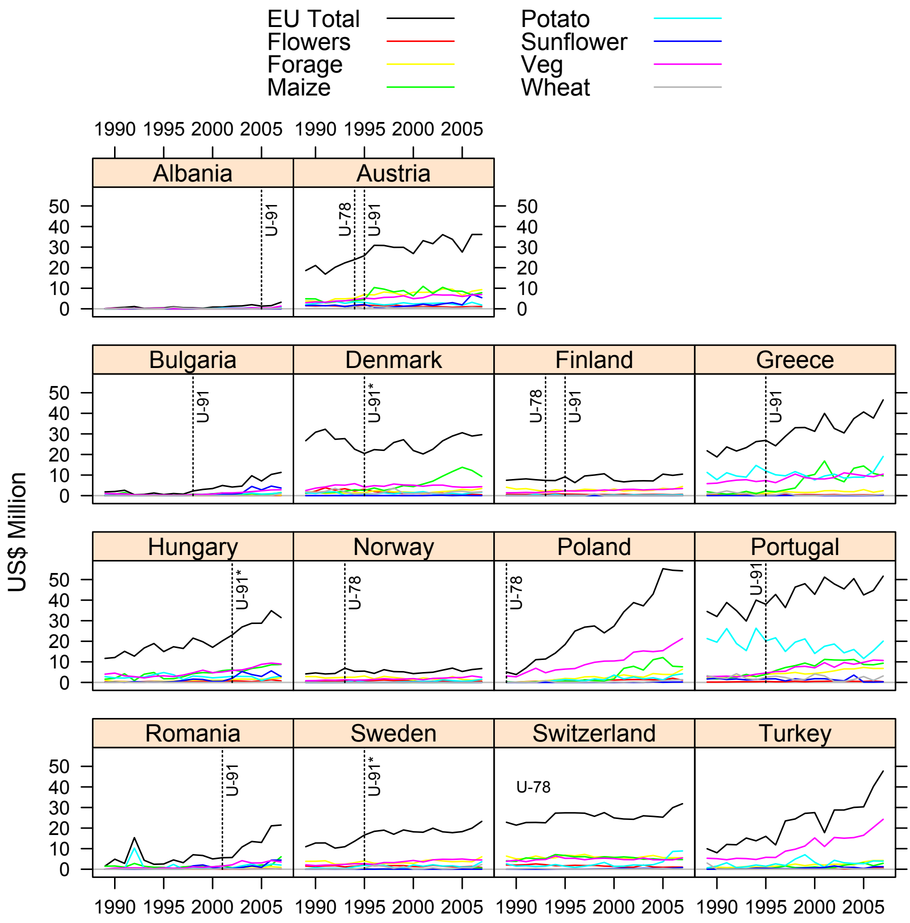


Figure 4.10: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 2 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

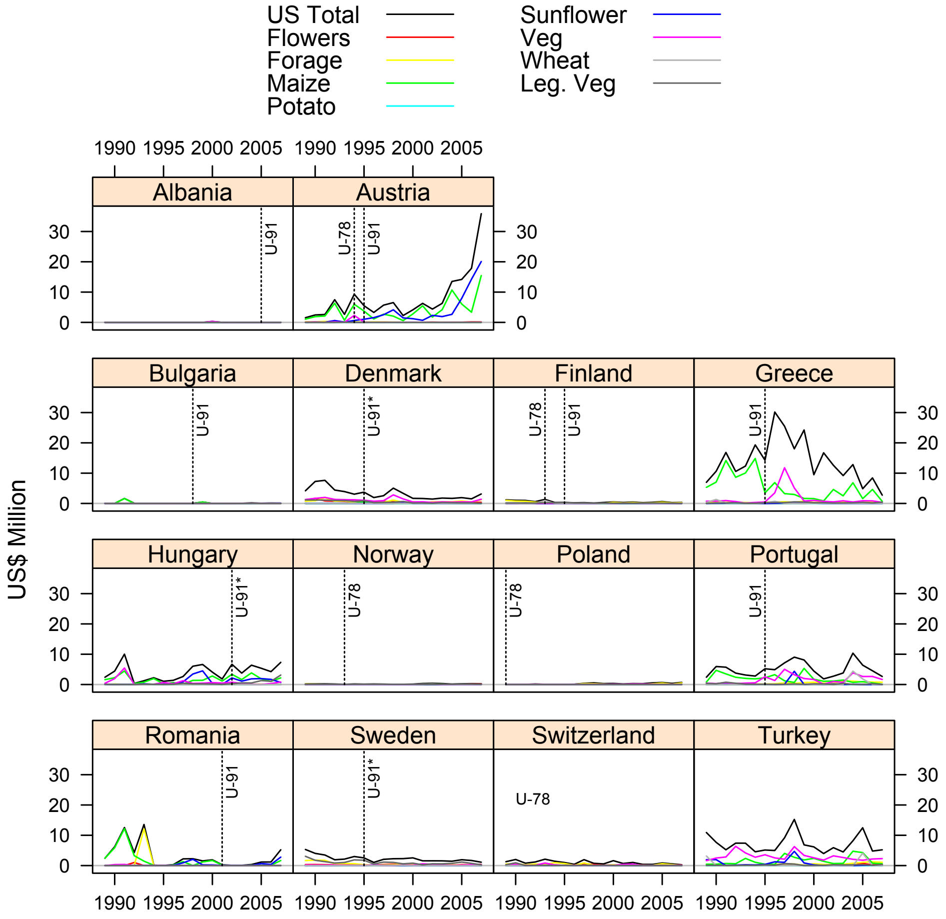


Figure 4.11: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 3 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

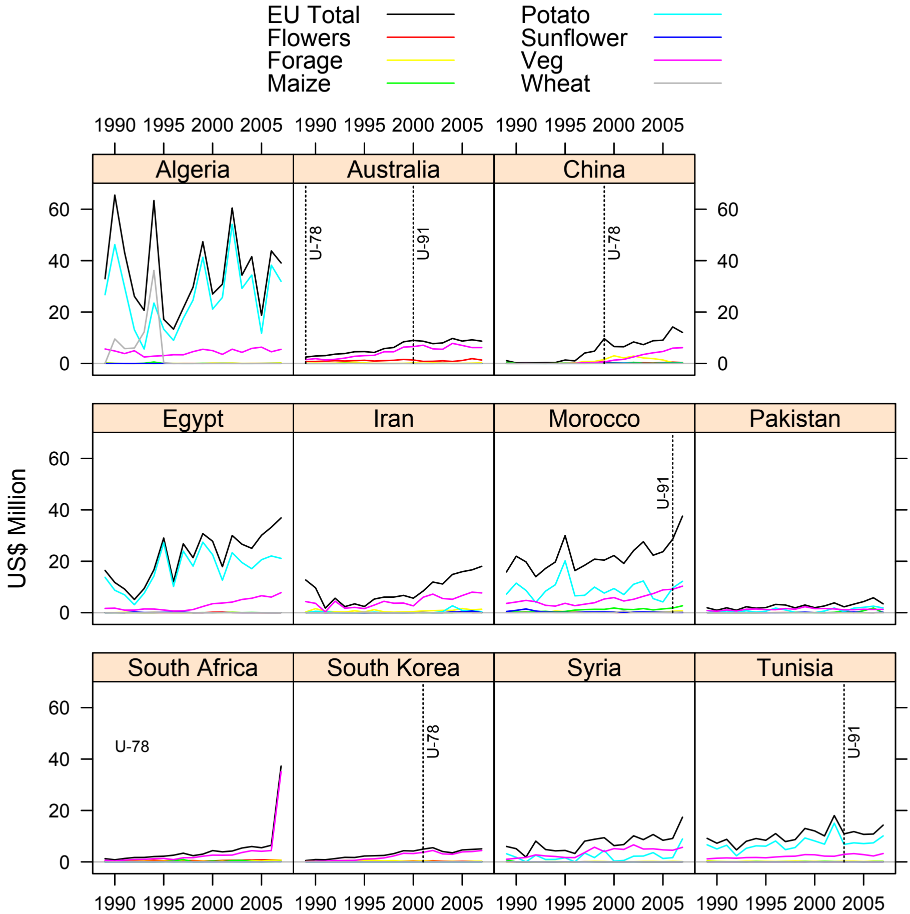


Figure 4.12: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 3 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

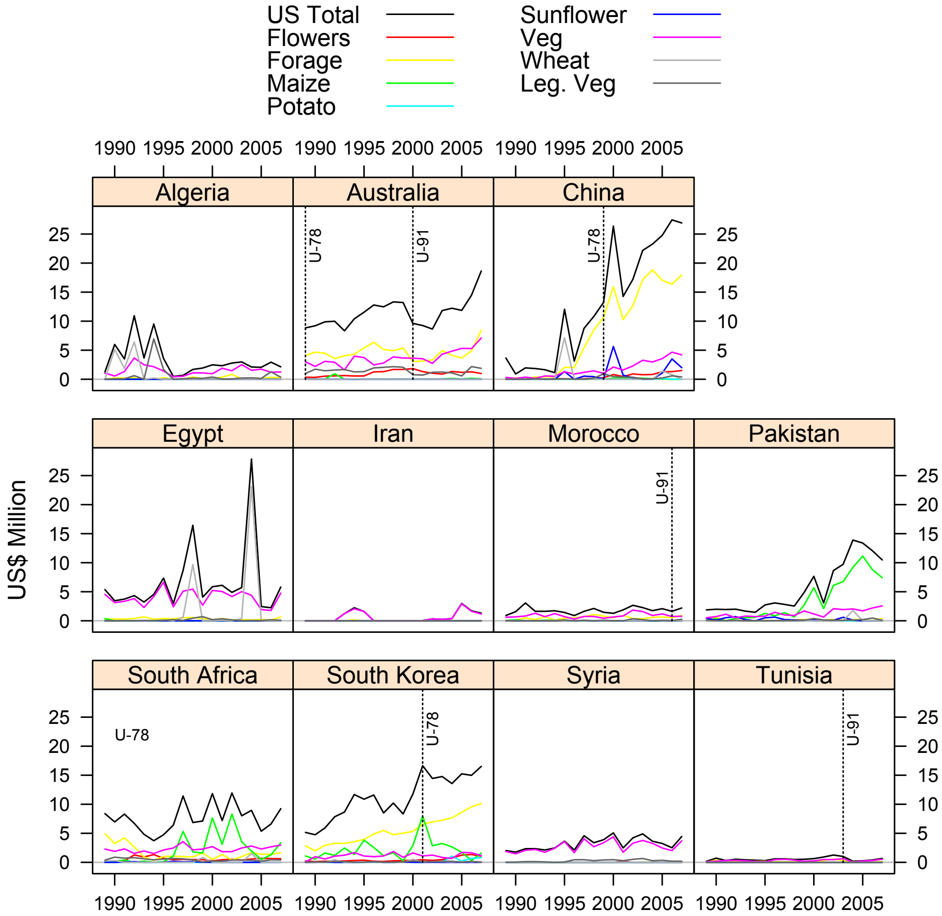


Figure 4.13: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 4 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

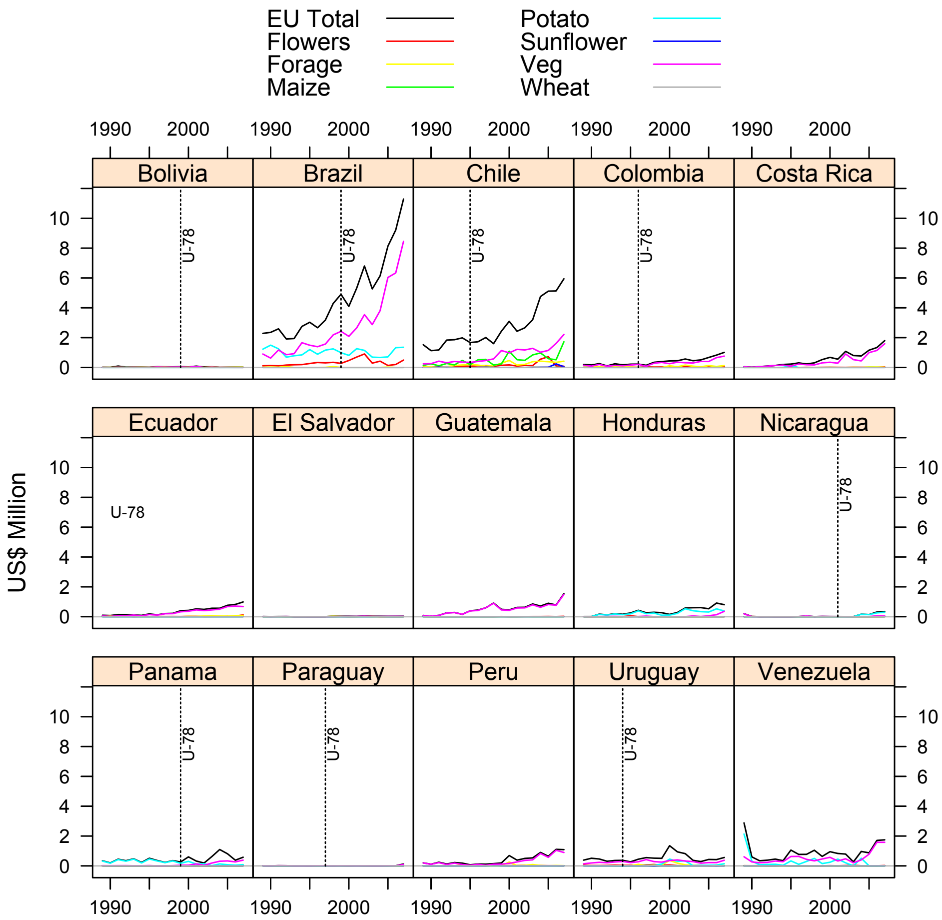


Figure 4.14: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 4 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

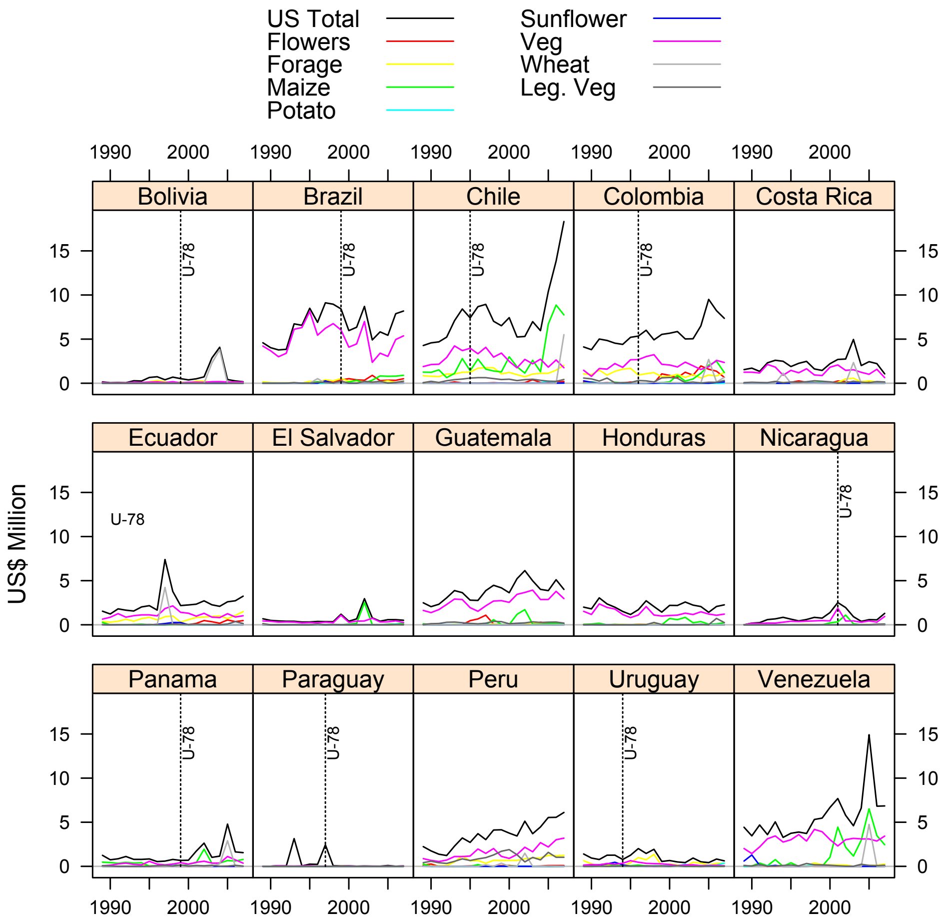


Figure 4.15: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 5 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

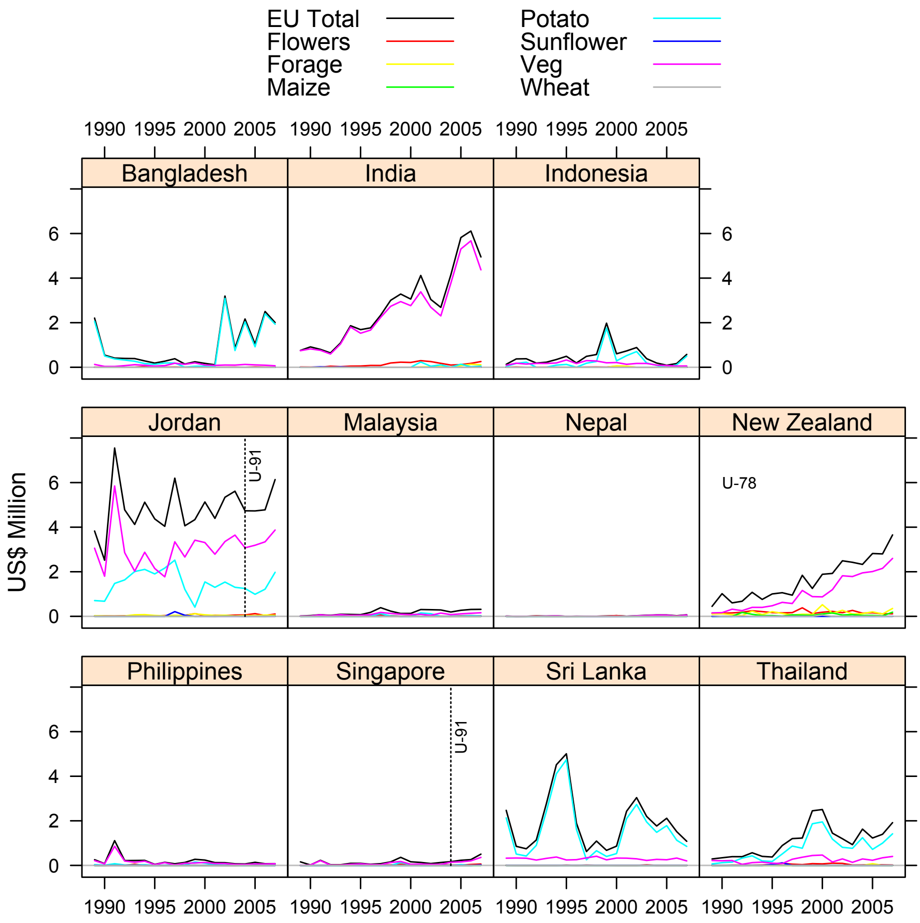


Figure 4.16: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 5 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

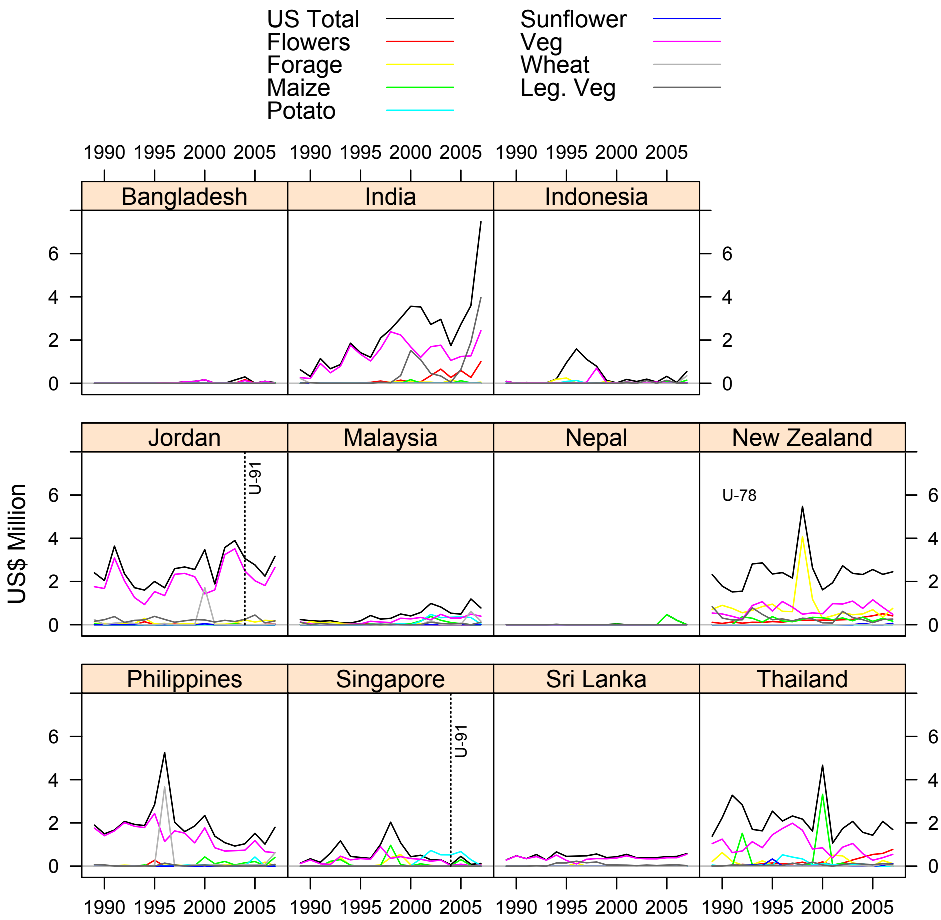


Figure 4.17: Seed imports (constant US$ 2000) by crop species from the EU for selected countries (1989-2007) - Group 6 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)

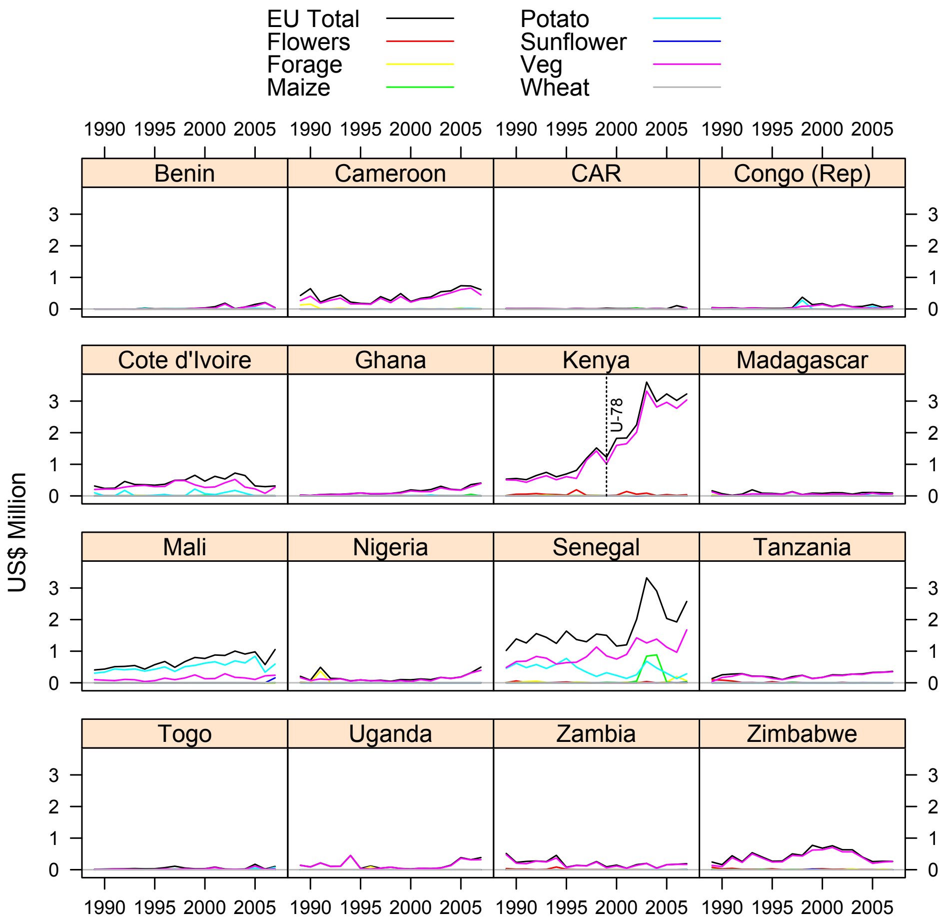
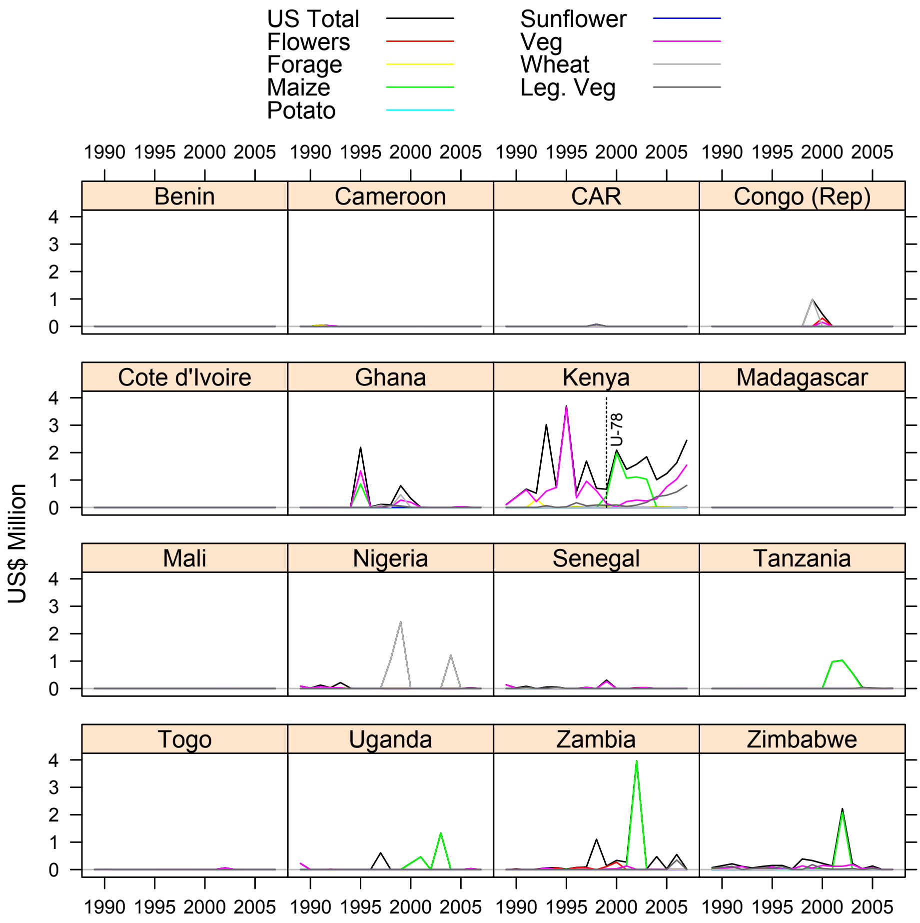


Figure 4.18: Seed imports (constant US$ 2000) by crop species from the US for selected countries (1989-2007) - Group 6 (Date of accession to UPOV 1978 or 1991 Acts is also indicated)



5 Experiences with IPRs in developing countries

5.1 Introduction

The Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) requires that all countries that are members of WTO provide a minimum level of intellectual property protection in their national laws. Article 27(3)b describes an obligation to provide some form of protection for plant varieties. The appropriate intellectual property rights (IPRs) may either be a version of plant variety protection (PVP) or patents. Developing countries were supposed to have such a system in place by 2000. Least developed countries were allowed a transition period until 2006, which was extended until 2013.

This requirement has stirred considerable controversy. The standard argument is that an IPR regime for plant varieties will stimulate investments in research, help develop the domestic seed sector, and allow countries to take advantage of foreign technology (e.g. International Seed Federation, 2003). Many observers, however, are more cautious about the possible benefits and see potential dangers in the concentration of technology ownership and restrictions on farmer seed systems (Commission on Intellectual Property Rights, 2002; Tansey, 2002). Additional concerns are raised when bilateral trade negotiations (particularly involving the USA) oblige developing countries to accept so-called 'TRIPS-Plus' agreements establishing IPR regimes beyond the minimum required by the WTO. Many NGO campaigns draw further attention to issues such as the 'patenting of food crops' by portraying small farmers as in imminent danger of being denied access to their seed.

This chapter examines the issue of IPR regimes for plant varieties by presenting experience from the field. It is based on a study commissioned by the World Bank and conducted in 2004 in China, Colombia, India, Kenya and Uganda.[1] The five-country

[1] This chapter is based on a study commissioned by the World Bank (Louwaars et al., 2005). The current author was the only economist in the core team and responsible for the economic soundness of the research undertaken, which involved other disciplines as well, and in addition, was also the lead person responsible for the case study in China, one of the two largest countries in the sample. This involved undertaking and supervising field research in China (a survey of key informants from the public and private plant breeding sectors and collection of quantitative data on the sector), and assuming responsibility for its incorporation in the final report (separate country reports were not produced). The results of the research were integrated thematically across countries (not by country) in one large report (Tripp, Eaton and Louwaars, 2006), of which the current author was second author (Available at `http://siteresources.worldbank.`

study team comprised nine people with a range of experience in IPRs, plant breeding and seed systems, including one specialist from each study country. The team spent five days together discussing key issues and developing interview protocols. Team members conducted interviews with a wide range of stakeholders, including regulatory and IPR agencies, private seed companies, public research and seed organizations, farmer organizations and NGOs. More than 240 people were interviewed for the study and relevant statistical data were also analyzed.

The paper concentrates mostly on PVP (the most relevant IPR regime for developing countries to date), but also discusses plant variety patents. It does not attempt to address patent systems for biotechnology, but does examine the protection of transgenic crop varieties. PVP regimes are in effect in only a few developing countries, and this paper attempts to summarize progress to date and, based on these observations, offers suggestions for the design and implementation of IPR systems for plant varieties.

The chapter is organized in the following way. The next section looks at what is known about the impacts of PVP in industrialized countries and describes alternative mechanisms for providing incentives for plant breeding and seed production. This is followed by a review of the types of appropriation that PVP may try to control (from other firms, large-scale informal seed sale, and farmer seed saving and exchange) and the effectiveness of various IPR alternatives. The paper then examines some of the administrative requirements of a PVP system. This is followed by a review of the major experiences to date with the protection of transgenic crop varieties in developing countries. The paper concludes with a brief summary of the arguments.

5.2 Impacts and alternatives

It is much too early to be able to do any type of quantitative study on the effects of IPR regimes on plant breeding in developing countries, but there have been several studies that have attempted to analyze the issue in industrialized countries. As might be expected, it is often difficult to separate the effects of other economic and policy changes from those of IPRs, and the lack of adequate baseline data further restricts analysis. Several studies document an increase in private sector breeding for a number of non-hybrid crops in the US since the PVP Act of 1970, but most attribute only a modest role to PVP for these changes (Butler, 1996; Lesser, 1997). (Penna, 1994) shows an increase in breeding investments in the UK for some horticultural crops, but not others, and Diez (2002) demonstrates that there have been more PVP certificates issued in Spain to private sector breeders for crops for which PVP protection was available earlier. An assessment of the effects of PVP in Canada found increased breeding investment for some horticultural crops, but less for field crops (Canadian Food Inspection Agency, 2001). For wheat, Alston and Venner (2002) show that private sector investment in US wheat breeding has remained static while that of the public sector has increased. These mixed results can be interpreted as

org/INTARD/Resources/IPR_ESW.pdf). This chapter 4 is the journal article (Tripp, Louwaars and Eaton, 2007) produced based on the report.

evidence that PVP provides incentives for breeding under certain circumstances, but not others. There is as yet little systematic research that addresses how the effectiveness of PVP is related to factors such as market size or additional protection mechanisms. While some observers conclude that PVP may not be strong enough to encourage investments in plant breeding (Alston and Venner, 2002) or see this as a rationale for genetic use restriction technologies (Srinivasan and Thirtle, 2003), the overall inconclusiveness also lends support to general skepticism about the role of IPRs in economic development (Chang, 2002; Helpman, 1993).

A second issue that deserves attention is the fact that seed and plant breeding industries have grown and developed without the presence of PVP. This is the case historically in the North and there are several examples of dynamic and productive seed sectors in the South (e.g. India) that have emerged and prospered without any type of PVP. This is not to say that new IPR regimes cannot make further contributions to seed system development, but it is important to consider the mechanisms that are already available to provide the type of incentives that PVP is supposed to offer.

One of the most important of these mechanisms is hybrid seed, the first-generation product of a cross between two (or more) inbred lines. The major attraction for farmers is that hybrid vigor contributes to higher yields as well as producing a more uniform crop. For seed companies, hybridization offers two additional advantages; the fact that second-generation hybrid seed loses at least some of its yield potential and its uniformity means that farmers are not likely to use saved seed; and the fact that the inbred parents are a form of trade secret keeps competing companies from producing the same variety. Hybrid maize provided the impetus for the development of the seed industry in the US beginning in the 1930s and is the basis of seed industry development in countries such as Kenya and Zimbabwe. When India's seed policy changed in the 1980s, it was hybrid sorghum and pearl millet that opened the door for a flourishing private seed industry (Pray et al., 1991). Non-hybrids (which will be referred to here as open-pollinated varieties or OPVs) are much more susceptible to appropriation and are less likely to provide profits for an emerging seed industry. The major exception is those crops (e.g. vegetables) where seed saving is difficult or inconvenient.

In addition, there are other legal mechanisms that can help plant breeders control access to their varieties. If national seed laws include mandatory certification, then it may be possible to control which company(ies) can produce seed of a variety by limiting access to breeder seed. A small seed company in Uganda has access to several public maize varieties which it sells in the domestic market (and also exports to Kenya and Tanzania), based on a contract with the national research institute (NARO) in conjunction with Uganda's mandatory certification regulations. Another strategy relies on the ability to enforce IPRs in output market countries combined with contracts for the use of germplasm in producing countries. For instance, a few firms control most of the rose varieties that are marketed in Europe. Many of these are produced in Kenya (which has a PVP law) and Uganda (which does not); the most important factor that keeps growers from overstepping the limits imposed by their royalty agreements is the fact that they are dependent on a major wholesale market in the Netherlands, where production can be monitored and PVP enforced. The strategy is particularly useful for crops such as ornamentals where the variety can be identified in the marketed product. Brands and trademarks are also important tools for developing seed markets. Many seed companies in India react to questions about imitations and misappropriation of their varieties by pointing to the importance of brand identity and customer recognition.

5.2.1 IPRs for plant breeding and developing countries

The most widely used *sui generis* systems for protecting plant varieties are those of the UPOV Conventions. The Union for the Protection of New Varieties of Plants (UPOV) was established in 1961 as discussed in chapter 1, and most industrialized countries, and a growing number of developing countries, are members of a UPOV Convention. The only two UPOV Conventions relevant to the discussion here are those of 1978 and 1991. Although many countries operate under the UPOV 1978 Convention, any countries that now apply for membership must do so under the 1991 Convention. For instance, Tanzania passed its Protection of New Plant Varieties Act in 2002, and although this is probably compatible with the UPOV 1978 Convention, it is not eligible. (India, whose application to UPOV is pending, has been granted dispensation to join under 1978, although it is not certain if its new law will qualify). The other option is utility patents for plant varieties, which have been granted in the US since 1985 and are used in a few other countries, such as Japan; this is not a feasible option for developing countries (as demonstrated below).

There are several important characteristics that distinguish the UPOV Conventions and plant patents and which deserve particular attention by developing countries who are considering one of these options or who are designing another *sui generis* system. Under UPOV 1978, member countries could designate which species or genera they wanted to include for protection, while UPOV 1991 requires that all crops are included, although allowing a phased expansion of coverage (recall Table 1.1). The minimum protection period also increased slightly under UPOV 1991.

A country does not have to be a member of UPOV to meet the TRIPS requirement for a *sui generis* system, but many developing countries at least model their legislation on UPOV 1978 or 1991. As of April 2006, UPOV membership for industrialized countries included 8 countries under the 1978 Convention and 18 under the 1991 Convention. The membership for countries classified as developing, newly-industrialized or economies in transition was 17 (1978) and 15 (1991). A number of other countries are at various stages of the application process. No countries in sub-Saharan Africa, South or Southeast Asia (except Singapore) or Latin America have yet joined UPOV 1991. However, the African Intellectual Property Organization (OAPI), constituting 16 (mostly francophone) countries in West and Central Africa, has implemented a single PVP system which entered into force in January 2006, and has initiated procedures to join UPOV 1991. The OAPI system represents a harmonized regional approach to PVP in which one application covers all member countries. This is similar to the service of the European Community Plant Variety Office (CPVO), although separate national PVP systems also exist in member countries. Several developing countries that belong to UPOV 1978 (e.g. Colombia and Kenya) are considering changes in their legislation to make it more consistent with UPOV 1991. The following discussion examines the degree to which IPR regimes in developing countries are able to address a breeder's concerns about competing firms and farmers. The discussion is based largely on experience from the five case study countries whose PVP legislation is summarized in Table 5.1.

5.2.2 The Performance of PVP

Protection from competing firms

As discussed in chapter 1 (and see in particular, Table 1.1), IPR systems for agricultural plant varieties are meant to control unauthorized commercial production of protected varieties. Where commercial seed production is based on hybrids, however, there is less incentive to apply for PVP, providing that seed companies can ensure that competitors do not gain access to their inbreds. For instance, even though Colombia has been a member of UPOV since 1996, MNCs and domestic firms market maize hybrids without PVP. On the other hand, about two-thirds of the PVP certificates issued for field crops in China are for hybrids or inbred lines. This reflects the importance of hybrids in Chinese agriculture (China is the pioneer in hybrid rice), but is also an indication of the difficulty Chinese breeders have in maintaining physical security for their inbreds, which may be stolen by competitors from seed production plots. Similarly, the Indian seed industry is planning to apply for PVP for most of its hybrids. Seed production for many crops in India is concentrated in specific zones that are agronomically suited for seed multiplication, and the presence of many competing firms working in a relatively few villages creates opportunities for the misappropriation of valuable germplasm.

Because it is straightforward to multiply OPV seed, firms have strong incentives to protect their varieties. In Colombia, domestic firms that breed and market rice varieties, and MNCs that market cotton and soybean seed, protect their OPVs with PVP. Argentina enacted PVP legislation in the 1970s and by 1994 nearly 80 percent of the PVP titles were for OPVs, mostly of field crops such as wheat, soybean and alfalfa. The National Seed Institute (INASE) was created to supervise the seed trade and to enforce PVP. A study showed that its ability to reduce the illegal trade in wheat and soybean seed by unregistered dealers and grain elevators helped save the small domestic seed companies who depended on these crops (Jaffe and van Wijk, 1995).

But even with PVP, controlling the informal trade in OPV seed among farmers (so-called 'brown bagging') may be difficult. One of the reasons that Colombia is considering tighter restrictions for protected varieties is that many rice farmers buy seed from each other rather than from the formal market. Such restrictions may be justified in Colombia, as most growers manage commercial operations (average 32 ha) and there

Table 5.1: PVP legislation in case study countries

Country	Legislation	Scope of coverage	Plant variety patents
China	Regulations of the People's Republic of China on the Protection of New Varieties of Plants (1999). Member of UPOV (1978) since 2000	41 crops currently eligible. Certificates have been issued for 15 species through 2004. (Cotton not eligible for protection.)	Hybrids may fall under scope of patents for 'a breeding or selection methodology'.
Colombia	Law 243 (1995) establishes PVP. Resolution 2046 (2003) defines limitations on seed saving. Member of UPOV (1978) since 1996.	All crops eligible. In practice certificates issued for 7 field crops and 15 horticultural crops.	Plant varieties cannot be patented but transgenic varieties may be patented because not found in nature.
India	Protection of Plant Varieties and Farmers' Rights Act (2001) establishes PVP. Implementation beginning in 2005. Application to join UPOV (1978) pending.	No crops excluded, but exemption for varieties whose commercial exploitation would be a danger to public order, public health, etc.	No patents of plant varieties allowed.
Kenya	Seed and Plant Varieties Act (Cap 326) amended in 1991 and 1994 to establish PVP. Kenya joined UPOV (1978) in 1999	No crops excluded; to date applications have been accepted for 31 field crops and 23 horticultural crops.	No patents of plant varieties allowed.
Uganda	Draft Plant Variety Protection Act is still before Parliament. It defines PVP as well as farmer and community rights.	No crops excluded in draft bill.	No patents of plant varieties allowed.

Source: Tripp, Eaton and Louwaars (2006) are half-a-dozen seed companies in the market offering a range of rice varieties. Kenya faces the same problem for wheat seed, and is considering a similar remedy (moving towards UPOV 1991); but Kenyan wheat farmers represent a range of farm sizes and the wheat seed is currently supplied by only one company, with strong government ties.

Despite the fact that PVP is welcomed by seed companies selling OPV seed, the case studies did not uncover much evidence that merely establishing a PVP law will elicit additional investment in plant breeding for OPVs. The question was pursued in interviews with seed companies in all five countries and there was almost universal agreement that PVP makes little difference regarding investment in OPV research. Colombia's rice seed industry was established before PVP came into force. Since the establishment of PVP there has been no move towards commercial breeding of OPV maize or beans, two important crops for Colombia's farmers. In Kenya, the seed companies place most of their efforts on hybrid maize (and the two companies that produce OPV maize varieties have yet to even apply for PVP). No Ugandan seed company yet has its own plant breeding capacity, but companies' plans focus on hybrid maize. OPV breeding in China concentrates on particular market niches and does not seem to have expanded with the advent of PVP; interviews with seed companies indicated that there was little immediate interest in exploring new possibilities for OPVs. A few Indian seed companies already market OPVs (e.g. rice, cotton, vegetables). They welcome the opportunity to protect these varieties but do not predict that they will expand their efforts in this area. Indian seed companies are more likely to pursue OPVs as a way into the more lucrative hybrid market; for instance, several companies have entered conventional rice breeding in the hopes that they can then take advantage of expanding opportunities for hybrid rice. None of the companies interviewed indicated that they would expand into breeding OPVs because of the introduction of PVP.

There is also little evidence that the establishment of PVP is, on its own, able to shift the priorities of public plant breeding. Most NARIs are already under pressure to generate more of their own revenue, and earning royalties from protected varieties is certainly an attractive strategy. In Kenya and Uganda, where hybrid maize is seen as the principal source of revenue, breeding investment in OPVs does not seem to be affected by PVP. Colombia's NARI is also under pressure to generate revenue, but there is no explicit strategy to promote OPV breeding because of PVP. China's situation is more complex. Many crop research institutes have been selling varieties or seed long before the introduction of PVP and institutional mandates have at least as much influence on breeding priorities. For instance, the Rice Research Institute in Hunan concentrates on OPV rice varieties and earns almost half of its income from seed-related activities. The Rice Research Institute of the Guangdong Academy of Agricultural Sciences receives extra government funding based on the adoption of its varieties, but even so the institute is shifting more towards hybrids because of the revenue generation possibilities. India's public research institutes and universities already invest a considerable amount in breeding OPVs, and interviews with research administrators revealed no immediate plans to shift strategies in response to the advent of PVP, partly because of the perception that any royalties will revert to the central Treasury rather than to individual institutes.

Seed saving and exchange

A major reason that PVP does not elicit greater investment in commercial seed production for OPVs is the problem of limiting farmers' seed saving and exchange. UPOV 1991 offers a solution to this problem, by prohibiting seed saving of protected varieties (except for specifically designated crops) and eliminating the possibility of seed exchange. However, for most farming systems in most developing countries such restrictions would be politically explosive and impossible to enforce among farmers who are used to saving seed or obtaining it from their neighbors.

Where robust and competitive seed markets serve commercial farmers it may be possible to selectively restrict seed saving if this has strong economic benefits. For instance, in the 1980's, while the Netherlands allowed seed saving for field crops (under its UPOV 1978 PVP law) it prohibited saving of planting material for flower crops. These contribute strongly to the Dutch economy and unauthorized use of planting materials was considered a significant disincentive for investment in breeding. Many EU countries now attempt to enforce UPOV 1991 restrictions on seed saving for field crops, but the implementation (in terms of royalty collection) is uneven. Small farms (defined in terms of land required for specific production levels) are allowed to save seed of protected varieties, while larger farms that save seed of these varieties must pay a royalty (defined by the EC as 50 percent of the retail seed price). The royalties are collected fairly efficiently in the UK (by the British Society of Plant Breeders) and the Netherlands (by the Certification Service) but less well in France (where many farmers refuse to cooperate with the scheme). Seed saving of PVP-protected varieties is permitted in the USA, but the expanding use of plant variety patents and grower ('shrink wrap') agreements means that farmers are restricted from saving seed of many commercial varieties. One of the few examples of an attempt to limit seed saving in developing countries is a recent ruling in Colombia that prohibits farms of greater than 5 ha from saving seed of protected varieties; it is too early to assess the performance of this ruling.

The new Protection of Plant Varieties and Farmers' Rights Act in India is of particular interest because it allows a farmer 'to save, use, sow, resow, exchange, share or sell his farm produce including seed of a variety protected under this Act' (Art.39(1)iv) in the same manner as before the Act's implementation. Given the fact that there is a thriving informal seed market in India, where certain farmers are recognized as good sources of seed and may earn substantial sums selling carefully selected grain to their neighbors, there are concerns that this Act may not even be compatible with the requirements of UPOV 1978. The Indian seed industry would have preferred more restrictions, but many domestic companies that already market OPV seed recognize the difficulties in even proposing stricter control, accept that their markets might not grow as quickly as they would hope, but believe they can still build a business on selling quality products. The examples of private OPV seed sales are mostly restricted to instances where seed saving is inconvenient or output markets demand high and uniform quality grain, but these are slowly growing in prevalence. In Andhra Pradesh, for instance, more than half of rice seed sale (all public varieties) is in the hands of private companies, while previously this was the exclusive domain of the state seed corporation (Tripp and Pal, 2001).

5.2.3 The administration and management of PVP

The costs of PVP

Choices regarding appropriate IPR regimes for plant varieties must take account of the costs of administering these systems. A PVP office entails considerable costs for a developing country, including access to adequate laboratory facilities and experimental sites, the development and maintenance of adequate reference collections, and the opportunity costs of assigning scarce, highly trained personnel to tasks such as DUS testing, which requires carefully managed field trials.

Some or all of these costs can be recovered in the fees charged for issuing PVP certificates. There seems to be no standard formula or strategy for setting PVP fees (Table 5.2). In the US, there is a charge for examination and certification but no subsequent annual charges. In many other countries initial application and testing charges are supplemented with annual fees. In Colombia, fees rise from the first through fourth year (as was the case in the EU until recently), while China's fees rise steadily throughout the lifetime of the certificate. Kenya's annual fees are uniform and the EU has just adopted a uniform annual rate. There has been little research on the implications of different fee rates and structures. In Europe, breeders regularly decide not to renew their PVP certificates (Srinivasan, 2003b), and although the costs of PVP may be easy to recover for widely sold varieties, it is not clear that varieties developed for niche markets or where demand from resource-poor farmers is uncertain will necessarily be able to meet these costs. The five-country study noted concerns among public and private sector breeders about the high costs of PVP. Koo et al. (2003) have examined the situation in China, where many public plant breeding institutes claim they do not have the funds to apply for PVP (Huang et al., 2003).

There are no easy answers for establishing appropriate fees. High fees may allow cost recovery (as intended in the North) but they can also discourage applications, especially from public institutes and smaller firms. In the South, low fees may be justified in early stages of seed market development, but such subsidies can place a burden on state resources. Setting fees by type of crop, market, or applicant may be possible, but any complex differentiation might add to the administrative burden. Cost saving can also be achieved by various types of measures and cooperation. If DUS testing is already in place (for variety release) then the PVP authority can rely on this system. In addition, the breeding organization may be required to supply some of the data. For instance, in France the first year of DUS testing for maize varieties is the breeder's responsibility and the PVP authority manages the second year of trials to confirm the results. A particularly important option for developing countries to

Table 5.2: Costs of PVP

Item	China	Colombia	Kenya	EU	US
Application	$217	$233	$200	$1,115	$432
Testing	$556	$1,396 ($155 if done abroad)	$600	$1,265-$1,490 (depending on type of crop)	$3,220
Granting of rights	-	$39	$240	-	$682
Annual maintenance fee (by age of grant)	(1-3): $181 (4-6): $236 (7-9): $306 (10-12): $398 (13-15): $517 (16-18): $672 (19-20): $874	(1): $78 (2): $155 (3): $233 (4-20): $311	(1-20): $200	(1-20): $540 (flat rate beginning 2006	None
Cost of PVP and 10 years of protection	$3,340	$4,311	$3,040	$7,780 (lowest example)	$4,344
Cost of PVP and 15 years of protection	$5,687	$5,866	$4,040	$10,480	$4,344

Source: Louwaars et al (REF); website of the European Community Plant Variety Office (www.cpvo.eu.int) (fees converted at 1.24$/euro); website of Plant Variety Protection Office of USDA (www.ams.usda.gov/science/pvpo/PVPindex.htm).

consider is regional cooperation. It is possible to obtain a DUS certificate valid in all EU countries, based on a test done in one member state. This is the basis for EU-wide PVP applications under CPVO (and a similar system has now been instituted for the OAPI-member countries of West and Central Africa). In Southern Africa, the members of SADC are developing a system of regional variety release, which could be expanded to include regional PVP management as well. For varieties that are already protected in the North (e.g. horticultural crops), developing countries can utilize existing test reports.

Enforcement

Enforcement is a particularly important challenge for PVP. Because PVP is a private right, breeders are responsible for collecting royalties and detecting violations of their rights. A PVP office may assist in court cases, but it is generally not directly involved in enforcement. Seed companies and public research institutes that hope to take advantage of PVP must learn that they will need to invest their own resources in monitoring and enforcement. In a recent case in Colombia, a seed company asked the PVP office to examine specific fields and confirm that the cotton being grown was a protected variety. The company could demonstrate that the seed was not legally acquired and pursued an out-of-court settlement. The profusion of fly-by-night seed producers in China has caused a number of the larger seed companies to pursue as many cases of PVP infringement as possible, in part to educate the court system, which has no experience in this area.

Extant varieties

When a country establishes a PVP system it must also decide what to do about existing varieties. If the purpose of PVP is to stimulate further research and not reward past accomplishments an argument can be made for denying any protection to extant varieties. Uganda's draft PVP legislation does not provide protection for extant varieties. China allowed protection for varieties that had been released within 4 years of the establishment of PVP, and Colombia (and India's new legislation) grants protection to extant varieties beginning on the date they were originally released. In contrast, Kenya has proposed a complete amnesty to all released varieties, allowing a full 15 years of protection. Because virtually all of the affected varieties are produced by the public sector, and because the precise rights to many of them are contested between the national research institute (KARI) and the Kenya Seed Company (which previously had exclusive access to all public varieties), the decision is hotly contested and is still not approved.

Public research

The Kenya case illustrates a larger dilemma for PVP, related to the management of national agricultural research institutes (NARIs). There is an expectation on the part of many policymakers that NARIs should contribute more to their own budgets by earning royalties on their plant varieties. While this is an understandable proposal (given pressures on reducing public expenditures), there are several concerns. First, it is not clear whether NARIs will be able to compete with the private sector in plant breeding for crops with high commercial seed demand. There are a few positive examples; Brazil's public research institute (EMBRAPA) earns royalties from a consortium of small and medium-size seed companies that produce and market some of the institute's maize hybrids and OPVs (Garcia, 1998). But as the commercial seed industry expands in many developing countries, NARI management and incentives may not be sufficient to keep plant breeders in the public sector. Second, NARIs face the question of how to share royalties with plant breeders working on commercial crops, while sufficiently rewarding plant breeders and other scientists working on crops destined for less commercial farming environments. Third, NARIs will have to strike a balance between seed companies' interest in exclusive licensing arrangements and the expectation of open access to publicly bred varieties. Finally, any NARI expectations for royalty earnings will need to be matched by additional investments in management and enforcement capacity. The case study countries are only beginning to address these issues.

Relation to seed law

It is also important to examine the relationship between PVP legislation and the rest of national seed law and regulation. In the first place, if we are concerned about promoting commercial seed system development, the priority in many countries should be the reform of conventional seed legislation. We have seen that in some cases attention to the administration and enforcement of seed regulation may provide as many incentives for seed production as the enactment of a PVP law. For instance, there are several efforts underway in sub-Saharan Africa to ensure that the variety release process is transparent and efficient, that seed certification is more rationally managed, and that regional harmonization is instituted to promote seed trade (e.g. Rohrbach et al., 2003).

In addition, there are cases where PVP may be administered from the same office as that responsible for seed regulation (e.g. seed certification or variety registration). In some instances, seed law may have to be changed to support PVP. In India, for example, although an official testing and release procedure has always been in place for public varieties, the products of private seed companies (so-called 'research varieties') did not have to obtain official release. Their sale as seed was subject only to requirements of truthful labeling. The revised Seeds Bill, however, requires that all varieties offered for sale must be included in a National Register of Seeds, which will demand performance testing before approval. Thus private companies in India have given up their freedom to sell varieties without passing performance tests in return for a tool for limiting seed sales by unregistered companies and a system of property right protection that can control appropriation by competitors.

PVP in practice

It remains to be seen what effect the establishment of PVP in developing countries will have on plant breeding or agricultural development in the long run. The discussion above has emphasized that seed industry development can take advantage of several other mechanisms that offer some degree of control over germplasm and that enforcement and administration limitations may limit the effectiveness of PVP instruments. Because very few developing countries have extensive experience with PVP, there is little evidence to examine. Table 5.3 summarizes data from China, Colombia and Kenya, which have between 5 and 10 years of experience with PVP. The Chinese situation is quite different from the others. A complex hierarchy of county- and prefecture-level public seed companies is being replaced by private seed companies and public research institutes selling seed to meet government demands for cost recovery. The incentives for PVP are thus quite high, and Table 5.3 illustrates the range of crops seeking protection. (The protection of ornamentals is not included in the analysis.) Whether PVP is eliciting additional investment in plant breeding or first helping to reallocate rights and responsibilities in a privatizing seed system is open to question. In Colombia and Kenya, on the other hand, the number of field crop varieties seeking protection is more modest and most PVP certificates have been issued for ornamentals. The very low level of protection of field crops in Kenya is partly the result of the on-going dispute over a possible amnesty for older public varieties. The only exceptions are barley (varieties developed for Kenya Breweries) and pyrethrum (whose production is destined for export and is managed by the Pyrethrum Board of Kenya).

The protection of transgenic varieties

Much of the discussion related to IPRs for transgenic varieties concerns the complex patents for the genes, tools and processes used in genetic transformation. These issues are beyond the scope of this paper, but it is worth asking what the performance of PVP legislation in developing countries implies regarding the level of protection required to encourage the development of commercially viable transgenic varieties for resource-poor farmers. There is relatively little experience to date, but the examples of insect-resistant Bt cotton and herbicide-tolerant Roundup Ready (RR) soybeans provide useful evidence.

India's experience with Bt cotton has attracted much attention. Its first Bt cotton varieties were developed through a joint venture between Monsanto and India's largest seed company, Mahyco, which it partly owns. Two Mahyco Bt cotton hybrids were released in southern India in 2002. There was no possibility of gene patenting in India, and the varieties were released before the PVP law was in place. The fact that the varieties were hybrids provided some protection (at least from farmer seed saving), but there have been widespread reports of underground seed markets and clandestine plant breeding to take advantage of the Bt gene (Jayaraman, 2004). Many looked to Indian biosafety agencies to control this situation, but they are not equipped or mandated to deal with illegal seed markets. The new PVP Act and Seed Law should provide adequate authority for controlling the formal marketing of Bt cotton varieties, but enforcement capacities remain to be tested and farmers will still be able to save and exchange seed. In the meantime, Monsanto's strategy has shifted towards technology provision, where it can earn income from licensing arrangements and shift responsibility for enforcement to local partners. A joint venture (Mahyco-Monsanto Biotechnology Ltd.) is licensing the Bt gene to other Indian seed companies (who are more willing to accept seed market imperfections). The contract is based on exclusive access to the biosafety data that is necessary for approving any transgenic variety.

Several Indian seed companies have begun marketing their own Bt cotton varieties, using the licensed gene in their own germplasm, and believe that the new laws offer them sufficient protection to invest in the technology.

Bt cotton in China is a particularly complicated story. Bt cotton varieties are available through a joint venture between Monsanto, Delta and Pineland, and the Hebei provincial seed company; and separate gene constructs and Bt varieties have been developed by public research organizations (Pray et al., 2001). The vast majority of these are OPVs. Many of the Bt cotton varieties face competition from widespread illicit seed multiplication and marketing, to the point that the legitimate varieties hardly command any price premium and offer few incentives for further investment. One problem is that China did not initially include cotton in the crops covered by its PVP law. The public sector Bt gene is patented, but there is essentially no enforcement capacity in place. Even rudimentary enforcement of China's variety release regulations (any cotton variety offered for sale must be officially approved) or of its licensing system for seed producers and traders would help control the illicit trade in Bt cotton. It is likely that China will continue to have uncontrolled markets for Bt cotton until more resources are devoted to enforcing existing laws. Monsanto's hesitation to introduce its most recent Bt technology in China is probably due to protection difficulties. As in India, the company also appears to be moving towards a strategy of licensing technology to Chinese companies.

In smaller cotton markets, it is possible to manage access to Bt technology by controlling the output system. A Monsanto Bt cotton variety was introduced in Colombia in 2004 (although it had not yet been registered for PVP) and the process has been carefully controlled through requirements for grower registration and designated ginneries (and a resolution making it illegal to save seed of GM crops). Similar controls of output have characterized the introduction of Bt cotton in South Africa (Thirtle et al., 2003)and Mexico (Traxler, 2006).

Herbicide-tolerant soybean is the most widely grown transgenic crop in the world. It has become very popular in Argentina (Qaim and Traxler, 2005) where although genes may be patented, Monsanto was unable to make an application on time, so its RR varieties are simply protected by PVP. But much of the RR soybean grown in Argentina is farm saved or informally traded. In Paraguay and Brazil RR soybean has gained great popularity based on black market seed sale. Because only a small fraction of the RR soybean seed used in these countries is from authorized sources, Monsanto is beginning to pursue legal proceedings for patent infringement against shipments of soybeans from South America that arrive in ports of European countries where the technology is patented. The solution that is currently under discussion is charging farmers a royalty based on grain sold at harvest, to be collected by grain dealers, processors, or farmer associations; one of the major points of disagreement here is farmers' insistence on their legal right to save seed.

These examples of Bt cotton and RR soybean illustrate the problems and prospects of protecting transgenic varieties. Controlling the use of transgenes by competing seed firms does not appear to be a problem. In most cases a combination of biosafety regulations (e.g. requiring field trials before approval) and variety registration requirements (backed by basic PVP) would limit misappropriation. Thus very restrictive IPRs (such as patents for plant varieties) are not needed to control competing firms' access to the transgenes. However, the cases of India and China show that keeping transgenic varieties from black market seed producers is a more serious challenge. The conscientious enforcement of basic seed laws that determine how varieties are approved for sale and how seed dealers are licensed would do much to limit this problem. As with other varieties, a major challenge is farmer seed saving, especially for OPVs. Where the sale of the harvest can be monitored, the technology owner can control access to seed or charge royalties on the harvest, but whether these administrative arrangements can function over wide areas remains to be seen. Prohibitions on seed saving (backed by patent law, strict PVP, or special decrees aimed at transgenic crops) will face significant enforcement problems, especially if they apply to small farmers.

The control over access to seed of transgenic varieties in developing countries will be less than that achieved by MNCs in industrialized countries. Patent law and strict forms of PVP might help, but as we have seen the principal problem here is enforcement. More attention to the basic regulation of seed markets would be an important first step in many cases. Biosafety authorities can assist, but they are not equipped to police seed markets. Adequate incentives and protection for transgenic varieties will come from a judicious combination of seed law, biosafety regulations and appropriate IPRs.

Table 5.3: PVP Applications and Grants in China, Colombia and Kenya

	China		**Colombia**		**Kenya**	
	Applic.	Grants	Applic.	Grants	Applic.	Grants
Field crops						
Barley					7	6
Beans					13	
Cassava					2	
Cotton			25	8	2	
Groundnut	10	5				
Maize	520	248			54	
Potato	7	1	5	3	4	
Pyrethrum					23	23
Rapeseed	38	11			14	
Rice	365	82	12	6		
Sorghum					7	
Soybean	30	19	8	2	7	
Sunflower					10	
Tobacco			4	3		
Wheat	84	21			30	
Other					24	
Pasture grasses					**10**	
Horticultural crops	**25**	**8**			**27**	**1**
Ornamentals	**N/A**					
Roses			448	279	248	61
Other			214	139	61	15
Other crops						
Coffee	N/A				4	
Fruit	18	8			5	
Macademia	N/A				11	
Sugar cane			5	5	6	2
Tea	N/A				33	
Other	**53**	**8**	**6**	**6**		
Total	**1140**	**411**	**727**	**451**	**602**	**108**
Field crops as % of total	92%	94%	7%	5%	33%	27%

Source: China: based on data obtained from Chinese Ministry of Agriculture through 2003; does not include applications made to Ministry of Forestry for woody species. Colombia: based on data obtained from ICA (Colombian Institute for Agriculture and Livestock) through mid-2004. Kenya: based on data obtained from Kenya Plant Health Inspectorate Service (KEPHIS) through mid-2004.

5.3 Summary

All developing countries complying with the TRIPS Agreement will soon have some form of plant variety protection system in place. The rationale for PVP is that by providing a means of controlling the use of new varieties, breeders will be able earn more income from their innovations and will have incentives to invest in further research, which will benefit society. However, research on the impacts of PVP in industrialized countries has shown mixed results. In developing countries there are questions about management and enforcement capacity, as well as a realization that demands for commercial seed are limited by factors beyond those associated with inadequate supply.

A basic PVP system will be able to keep firms from appropriating varieties developed by their competitors and will help public research establish clear mechanisms for the production and marketing of its varieties by the private sector. This is a positive contribution, although several mechanisms already exist that help provide this type of protection. PVP should also help control the large scale informal production and sale of protected varieties, which can be an important measure for supporting legitimate seed firms, assuming they are operating in competitive seed markets. Again other mechanisms (such as basic seed law) can also be used to control this type of misappropriation. The other type of 'competition' faced by seed companies is farmer seed saving, and there is less that PVP can realistically do to address this factor in developing countries. In most cases attempting to control seed saving is infeasible and unwise, given the nature of subsistence farming systems. There may be rare exceptions for crops of high economic value grown by commercial farmers, but for the near future policymakers should see the development of agricultural markets that demand high quality produce as a much more reasonable way of encouraging farmers to turn towards commercial seed markets.

Despite the limitations of PVP, policymakers need to give attention to developing appropriate legislation that fosters seed system development. Although the immediate impact of a PVP regime on plant breeding and seed production may be quite modest, it is possible to get it wrong. In particular, there are dangers of establishing a PVP regime that is too rigid, reducing the flexibility required in the early stages of the development of commercial seed systems, or imposing administrative and enforcement burdens that are too costly or impossible to fulfill. Even the introduction of transgenic varieties does not require excessively rigid IPR regimes.

PVP should be seen as part of a broader strategy for the development of commercial seed provision. PVP must be compatible with other seed law, and in developing countries where formal seed systems are just emerging the efficient and transparent management of regulations for seed marketing, variety registration, and seed certification and quality control can do more to encourage commercial seed development than the establishment of PVP. It is important not to lose sight of the fact that IPR regimes such as PVP are established to help achieve societal goals. Policymakers in developing countries should view PVP as a tool to be adapted and used for achieving national agricultural development goals rather than an obligation imposed by industrialized countries. Meeting those goals requires an understanding of the circumstances of different classes of farmers, an analysis of the requirements of different types of commodities, and a capacity to target IPR regimes accordingly.

6 General discussion and conclusions

This concluding chapter begins with a summary and synthesis of research findings, followed by a general discussion of policy implications. The chapter concludes with some reflections on future research directions on the economics of IPRs in the plant breeding sector.

6.1 Summary of research findings

The preceding three research chapters have examined different aspects of the overarching question posed in the introduction: what form and scope of IPR protection should countries offer. One specific theoretical question and two empirical ones have been investigated in some detail. The empirical analyses are not, strictly speaking, an investigation of the propositions emerging from the theoretical analysis. The latter is intended to help inform systematic thinking about the issues at hand. As highlighted in the review presented in chapter 2, existing literature has not yet incorporated a number of important aspects that weigh on the assessment of what optimal IPR protection should be, despite considerable advances in recent years. The empirical analyses in the last two chapters provide evidence of the effects of PVP in particular on trade and investment considerations and contribute therefore to the growing body of studies reviewed in chapter 2. These new contributions should help to refine further theoretical consideration of these specific IPRs, with some suggestions for this provided below in sec. 6.3.

6.1.1 IPRs in intermediate goods

The theoretical analysis was based on a model of innovation in an intermediate good, represented by a vertical product differentiation framework, in the tradition tracing its roots back to Mussa and Rosen (1978). The model elaborated on the nature of tradeoffs involved in the scope of IPR policy in terms of the level of appropriability available to a monopolist innovator. The analysis highlighted how heterogeneity among farms leads to differing interests. More productive farms may benefit from a higher level of appropriability as they are able to profit more from the resulting higher level of innovation and quality in the intermediate good. Less productive farms, in contrast, would benefit from a more moderate level of appropriability so that they could afford the intermediate good, including possibly pirated copies. In this kind of model, farms definitely have an interest in some positive level of appropriability, as otherwise there would be no investment at all in innovation. Consumers, for their part, would benefit from lower prices, as the final good is homogenous, and this can be achieved with a moderate level of appropriability, thus maximizing the number of farms able to produce. This result may be contingent on the situation analyzed here, in which seed consitutes a process innovation enhancing farm productivity, as opposed to a product innovation with direct benefits for consumers, through for example, characteristics discernible to consumers, such as colour, taste, nutritional benefits, etc.

By explicitly modeling the intermediate good nature of seed, the analysis introduces an interdependence between farms who all compete in the production of the final good. The output price that farms receive depends on the number of them that are able to produce. This in turn is influenced by the combination of quality and price of the seed input. In this model, the monopolist anticipates these effects and selects quality and price to maximize profit. Higher appropriability encourages higher quality but also higher prices for seed, and some farms are not able to produce. The aggregate profits of the farm sector may well be increased, along with those of the innovator. But less productive farms and consumers will be disadvantaged. This provides an explanation for the observed alignment of interests in policy discussions concerning IPRs, with seed companies finding allies for stronger IPRs in more efficient, large-scale farms, who are opposed by small-scale farms with some support from consumer groups or civil society organizations.

Extending the analysis to a setting involving two countries, North and South, confirms earlier results using different types of models. In the absence of domestic innovative capacity, both farms and consumers in the South benefit most from minimal appropriability as diffusion of the seed is maximized at lowest cost by the possibility of pirating. When trade in the final farm product is introduced, farms in the North find themselves competing with those in the South, and the former will have an interest in seeing appropriability increased in the South, in order to reduce this competition (e.g. Sobolevsky, Moschini and Lapan, 2005). These results are very static in nature though, and addressing this limitation is acknowledged below as a possible line of further research.

6.1.2 IPRs and trade in agricultural seeds

The empirical analysis of international trade has failed to find any significant effect of the introduction of PVP in a country on its imports of agricultural seeds from the EU or the US. Given that the results in chapter 4 confirm, to a certain extent, earlier work on average US seed exports by Yang and Woo (2006), the analysis employed quantile regression techniques, recently extended to both static and dynamic fixed effects models, to explore for possible effects of PVP for countries with either lower or higher levels of seed imports, which might not be detectable with mean regression techniques. The approach taken, including the use also of poolability tests, highlighted the potential for erroneous inference. In the end, the analysis here, using a more comprehensive approach and dataset, is still consistent though with the earlier result.

These results suggest two possible explanations. First, other factors, including tariffs, specific regulations (such as varietal testing or sanitary or phytosanitary regulations) may play a more important role than IPRs in affecting trade in this sector. Such additional factors may not have been adequately captured in the existing dataset used. Relatedly, for certain grain and oilseeds crops, the patterns of trade may be affected more by the growing share of genetically modified crops, and their specific trade frictions related to biosafety regulations and consumer concerns. This does not necessarily imply that PVP is not important; it may play more of a role in stimulating investment, either domestic or foreign in origin, rather than influencing trade.

A second explanation is that the implementation of PVP in many countries has still not led to a system of IPRs that are sufficiently effective to provide incentives for trade and perhaps investment. Some possible reasons for this are provided in the complementary empirical analysis presented in chapter 5. It should be pointed out that the analysis has not incorporated a measure of effectiveness of PVP protection due to lack of data. And the lack of explanatory power in the model and specification has to be acknowledged and improved in future work (as discussed below).

6.1.3 PVP and plant breeding actors and investments

The empirical analysis of five country experiences (China, Colombia, India, Kenya and Uganda) with implementing PVP, presented in chapter 5, indicates that the effectiveness of this form of IPR protection is not yet very high, even in countries with some longer experience, thus supporting the second explanation above. In general, weak IPRs reflect the institutional capacity of public agencies in such countries, as these are responsible for establishing a system for granting rights. In many countries, plant breeding companies are cautious to submit varieties for testing for the criteria of distinctness, uniformity and stability (DUS) if they have concerns about the security of the testing procedure, including the integrity of the officials involved. New varieties could fall into competitors' hands before they have even been granted PVP protection. In addition, breeders require some degree of confidence in the specific legal channels by which alleged infractions of PVP titles may be pursued. In general, these findings provide some support to the second explanation that PVP has not affected international trade in seeds due to the PVP systems in developing countries still being insufficiently effective.

The findings also indicate that PVP is likely to be more effective as a means to prevent unauthorized multiplication and commercial sale of seed of protected varieties, than as a means to limit seed saving by farmers. The costs of enforcing the latter practice are generally too high in developing countries and the issue is highly controversial. One reason for this is that limiting seed saving may have consequences for food security at a local level. PVP might begin to play a role in ensuring transparency and removing information asymmetry in seed markets, which would also contribute to enhanced competition and thus innovation among breeding companies.

Three of the five countries studied have systems that have been granting PVP titles for some time, and applications are regularly being submitted. The evidence, based also on surveys of reported behaviour or perceptions, reveals though that the introduction of this specific IPR may have some unintended consequences and is certainly not following standard economic theory. This theory has not devoted much attention to the effects of IPRs, including PVP, on public sector research organizations, including government-funded research institutes and universities. The behavioural response appears to be related to the objectives of the public sector organization. In some cases, the potential ability to earn revenue is encouraging such organizations to pursue more commercial objectives. In other cases, public sector organizations view the availability of PVPs as a tool to stimulate diffusion of their innovations as it provides a means to grant seed companies an exclusive license to market a protected variety.

6.1.4 Synthesis

So what does this thesis add in terms of our knowledge concerning IPRs in the specific case of the plant breeding sector? Recent years have witnessed a surge in economic research on the effects of IPRs, with most attention focusing on the patent system. The agricultural sector has been the subject of some of these efforts, as reviewed in chapter 2, though not to the same degree as information and communications technology, or pharmaceuticals. The chapters of this thesis contribute to improved understanding of IPRs in the agricultural sector, and particularly the specific system of PVP developed as an alternative to patent protection.

Patents are expected to have two principal effects: stimulate innovation directly and also do so indirectly by promoting disclosure and dissemination of knowledge. In some seminal models, these effects were tempered by a temporary restriction on diffusion due to monopoly pricing (Nordhaus, 1969a). More recently, it has been recognized that patents may also encourage diffusion by providing a basis for licensing, including across international borders (Landes and Posner, 2003; Scotchmer, 2004). PVP is somewhat different from patents in that only the first principal effect is applicable. Breeders are allowed to maintain secrecy concerning how they produced a new plant variety in terms of the parental lines crossed. But the design of PVP, with the breeder's exemption, is specifically intended to be different from patents in order to ensure that subsequent innovation by competitors is not restricted by exclusive rights granted (the protected material may be used in further breeding efforts without any specific permission).

The effect of PVP on innovation has been examined in two ways in the current thesis. First, a theoretical model has been developed that assumes that this IPR provides a means of capturing exclusive rents, though imperfectly, in order to examine the specific characteristics of this sector, with relatively numerous, intermediate producers purchasing the protected innovation, possible providing themselves competiton to the innovator, and producing a homogeneous product for consumers. It should be noted that robust empirical evidence on this incentive effect of PVP has not been found in the literature. For example, Alston and Venner (2002) found little effect in wheat in the US, where public sector breeding still dominates. Moser and Rhode (2011) found little evidence of increased innovation arising from the US Plant Patent Act of

1930 for asexually-reproduced plant species. Moser, Ohmstedt and Rhode (2012) find that even the extension of utility patents to hybrid maize in the US in the 1980s did not lead to noticeable improvements in growth in yields, and some earlier studies are reviewed in Lesser (1997). But these studies have been limited in number and very few look at the specific effects of PVP. The theoretical model of chapter 3 does reflect, through its incorporation of the ease of reproducing seed, a mechanism explaining in part when such IPR protection will be less effective. Indeed, the relative ease of copying or reproducing a product is one of the key characteristics identified by Boldrin and Levine (Boldrin and Levine, 2008b, 2013) influencing whether a patent system can be expected to deliver net social welfare gains.

The treatment of heterogeneity among the purchasers of the innovation is relatively new in the literature, though it has been prominent in models of copyright protection and software or music piracy, as noted in chapter 3 (Belleflamme and Picard, 2007; Yoon, 2002), which are also developed in a vertical product differentiation setting. An appreciation of heterogeneity among farmers also features in chapter 5 and how the empirical studies were conducted in the five countries. There it was seen that a certain group of farmers perceive themselves as being able to benefit from stronger PVP, provided that brings enhanced innovations in the seed sector. Others, generally those who are less commercialized are much more concerned about their disadvantage relative to the first group worsening. This conflict of interests among farms concerning the introduction of new seeds also received attention in Lipton and Longhurst's (1989) review of the Green Revolution in Asia. In that analysis, negative effects on less efficient farms were judged as being mitigated in part through increased demand for labour by more productive farms. The analysis in chapter 3 does not incorporate any consideration of a labour market, but nonetheless reflects the basic competition between farms with different endowments and productivity.

Balancing different interests and the effects of IPRs on their welfare requires some intermediate breadth of protection, depending on circumstances. This was an original finding of Nordhaus (1969a) with respect to the length of protection determining the tradeoff between dynamic benefits from innovation and static losses from monopoly pricing. This theme has carried forward through the literature in terms of the optimal breadth of protection being one that is strong enough to encourage innovation, but is not too strong as to inhibit sequential innovation (Green and Scotchmer, 1995; O'Donoghue et al., 1998; Yerokhin and Moschini, 2008; Scotchmer, 1991). Furthermore, theoretical reasoning in chapter 3 indicates that countries may be expected to have different optimal levels of protection. The specific setting of an intermediate good produced by heterogeneous final producers is different than existing literature (e.g. Helpman, 1993; Grossman and Lai, 2004) but the results are generally consistent. The theoretical result also reflects the experiences emerging from developing countries as seen in chapter 5, which highlights the very different interests among those countries, but also within them.

Thus heterogeneity among actors within a sector is a unifying theme in the thesis although it must be admitted that the treatment has still been relatively simplistic and by necessity selective. The theoretical model of chapter 3 has incorporated heterogeneity among farms, but maintained a monopolistic breeding sector and been restricted to a unitary elasticity of final demand. In contrast, chapter 5 has investigated the diversity of actors involved in the plant breeding sector in the case study countries, including the relationship between public and private sector organizations, and between those conducting upstream research, including on biotechnology and genomics, and those involved more in traditional breeding and seed production. The importance of heterogeneity was also prominent in the econometric analysis of international trade in seed in chapter 4. There it was seen that US and EU seed exporters seem to be influenced by different explanatory processes and that the same holds true for countries importing seed. This implies a need for an alternative and more satisfactory theoretical model for these trade flows, which will most likely need to address heterogeneity among crops. As has been noted, crop species differ in the ease with which they can be reproduced (and 'pirated') and this is likely to influence trade decisions. This and other avenues for further research are discussed below.

The effect of PVP on trade is related to the growing interest in understanding the potential role of IPRs as a basis for stimulating diffusion, despite the traditional concern with restricted diffusion due to pricing above marginal cost as mentioned above at the start of this subsection. This basis is arguably stronger for international than domestic trade, given the possibility for innovators with monopoly power to price discriminate between foreign markets (van Dijk, 1995; van Tongeren and Eaton, 2004). This does though presuppose that reproduction of a protected good is not possible unless it has been marketed in the country in question.

Recent research on the patent system has started to examine the effect that this IPR may be having on the direction that innovation is taking. For example, Moser (2013) suggests that historically patent protection has channelled research and development efforts towards sectors in which protecting innovations through secrecy was more difficult, or became more difficult through technological developments. Such a potential mechanism within the agricultural plant breeding sector is examined in chapter 5, highlighting that in developing countries, PVP may influence the research directions chosen by public research organizations. Such an effect is not represented in the theoretical model of chapter 3 and interesting insights might be expected more from further empirical work, as suggest by chapter 2.

Assessing the results as a whole, it seems hard to avoid the conclusion that still relatively little is known about the effects of IPRs in the plant breeding sector, and particularly PVP. Mixed results on the impacts on innovation and diffusion are clouded by question marks concerning the effectiveness of protection offered. This refers less to the ease of 'pirating' as developed in the theoretical model, and more to whether the system functions in practice as expected on paper. As discussed in the introductory chapter and also in chapter 2, the design of PVP is intended not only to offer a form of protection that for new plant varieties that is tailored to specific technological characteristics of this type of innovation, but also to reduce transaction costs relative to the patent system. On the other hand, as revealed in chapter 5, developing countries appear to be struggling to implement the systems effectively, which is generating higher than expected transaction costs for their users. This is a very likely explanation behind the finding in chapter 4 of practically no effect of PVP on international trade in seeds. Before turning to possible avenues of further research in more detail, the following section first discusses the policy implications of these findings.

6.2 Policy implications

Some of the possible implications for policy have been discussed somewhat in each of the respective chapters. The theoretical model highlights that broader scope or enforceability of IPRs may increase innovation but a policy of maximizing innovation can disproportionately affect different groups of producers and consumers. The findings here suggest that not all producers benefit from increased innovation, nor do all consumers. While there may be cases where maximizing innovative efforts and outcomes results in greater overall benefits, including for most groups, this thesis has provided one plausible case where this is not so. In addition, the analysis supports numerous findings elsewhere that maximum appropriability is not a necessary condition for maximizing welfare, even in the aggregate (Grossman and Lai, 2004; Helpman, 1993).

Relatedly, the analysis has highlighted how IPR policy, as a component of innovation policy, may need to take into account the special nature of food as an economic good constituting a basic human need. Increasing innovative efforts and outcomes, through broader IPRs, might not necessarily improve the availability of food for all consumers, nor access to it. The limitations of the analysis in the thesis caution strongly against an unequivocal position on this issue. The static nature of the analysis treats innovation in a fairly simplistic manner, with little attention to its fundamental importance for long term productivity improvements, which are also necessary in the agricultural sector from a food security perspective. Yet, if policy to stimulate innovation relies primarily on IPR policy with consequences on diffusion and the availability of critical inputs such as seeds, then food security objectives might be compromised. This points to the familiar theme that multiple objectives - in this case productivity improvements along with food availability and access by consumers - may require multiple policy instruments. This thesis has not though explored the composition of the optimal policy mix. This might include stimulating innovation through subsidies or even public provision in order to ensure maximum diffusion, as has generally been the case historically in developed and developing countries. Alternatively innovation might be maximized through IPR policy while redistributive or targetted measures are deployed to ensure access by lower-income consumers to food. The analysis here has pointed to the potential need in such a scenario to also develop instruments to increase access of farms to higher quality and priced seed inputs.

The case for different levels of appropriability provides support to the proposition of maintaining existing flexibilities in the TRIPS Agreement. One of the most relevant is the ability of countries to provide for protection of plant varieties through PVP and/or patents (Article 27.3(b)). The interpretation of what constitutes 'effective' protection in this case could also provide room for flexibility in the scope of PVP, particularly as concerns the possibility for allowing the granting of a farmer's privilege. The 1978 Act of the UPOV Convention does provide for more flexibility in this regard than the 1991 Act. Developing countries may thus have more choice and options in tailoring IPR policy to the level of appropriability best matching their circumstances if they are able to still join UPOV under the terms of the earlier Act, as part of their fulfillment of their TRIPS obligations. Such flexibility would be similar to the approach followed by many developed countries who have only increased the scope of PVP in gradual steps over decades. A number of advanced economies, such as Canada, which does have a strong plant breeding sector, have yet to adhere to and implement the 1991 Act of UPOV. The possibility to implement PVP according to UPOV 1971, including for a limited number of crops, is thus also a relevant option for countries negotiating bilateral trade and investment agreements with the EU and the US, rather than accepting obligations that are even stricter than those under TRIPS.

The empirical analysis of experiences in developing countries from implementing these obligations also provides support for maintaining an international regime that permits flexibilities in implementing PVP. The results support a continued extension of the deadline for least developed countries to comply with Article 27.3(b), since this seems to be providing little immediate benefit in many cases, but does place demands on scarce administrative and institutional capacity in such countries. The results from the five case study countries support the recommendation that TRIPS obligations should not include strict requirements regarding seed saving and the elimination of the farmer's privilege. With respect to institutional design, developing countries can certainly benefit from strategies to reduce the costs of implementing PVP, such as acceptance of testing reports from other countries, or even direct pooling of resources at the regional level in the administration and enforcement of PVP rights. Such an approach has been pursued, for example, by the member countries of the African Intellectual Property Organisation (OAPI).

The reactions in developing countries of public sector breeding organizations to the introduction of PVP and patents indicates that some are viewing this as an opportunity to earn additional revenues. This may seem particularly attractive in times of decreased funding from government. While PVP is generally considered to be an instrument of innovation policy that is intended to stimulate private investment flows, the findings suggest a need for agricultural R&D policy makers to assess and define clear mandates, objectives and success criteria for publically funded research organizations. The most relevant role for such organizations in developing countries is to concentrate on diffusion goals, which may be promoted through a judicious use of PVP to facilitate commercial production and marketing, or on the development of improved crop varieties for either poorer farmers or marginalized environments for which private sector incentives are not likely to be as strong.

The lack of effect of PVP on trade in seeds does though pose more fundamental questions about the rationale for the TRIPS Agreement, or at least specific provisions such as the requirement that protection is offered for all crop species. As explained above, either there are other factors that are more important than PVP in influencing international seed trade, or many countries have not yet been able to develop sufficiently robust PVP systems. Both cases imply that there might not be very much that is trade-related about IPRs for plant varieties, despite the name of the international agreement requiring its adoption by all WTO members.

6.3 Future research

There are many remaining questions concerning the optimal IPR policy for the plant breeding and crop genetics sector. The understanding of some of these questions could benefit from further development of theoretical models to support reasoned insights of likely impacts of proposed policies, particularly given the continued push by some seed companies for broader IP protection for seeds (Janis and Smith, 2006). At the same time, there are clearly a number of issues in which empirical research is necessary to understand the relative importance of the various causal mechanisms seemingly at work in IPRs. As an aside, it is worth highlighting that the literature is, in general, searching for an understanding of the effects of IPRs, even in terms of straightforward incentives to innovate which is often just assumed or taken for granted (see, for example, Bessen and Meurer, 2008b; Boldrin and Levine, 2008a, 2009; Jaffe and Lerner, 2004).

This thesis has only begun to explore the potential implications of IPRs in an intermediate good setting. A number of extensions to the analysis presented here can be considered, which would help verify whether this setting provides for different balancing of tradeoffs as compared to the conventional analysis concentrating on final goods markets or process innovations. The question of investing in innovation of an intermediate good could be analysed in a dynamic setting, incorporating the specific features of sequential and cumulative innovation (see, for example, Moschini and Yerokhin, 2008). Further work could usefully explore the outcomes of strategic interaction between competing breeders, including a generalized formulation of final demand and possibly also exploring whether the distribution of farms plays a role. One aspect of dynamics not modelled is structural change in farm production. The ownership of farms that are not able to produce may plausibly be transferred to more productive farms leading to a process of consolidation (horizontal concentration) and increase in average farm size. In terms of the formulation in chapter 3, such a process is more likely to be the case if the basis of heterogeneity reflects characteristics of farm managers, as opposed to inferior physical or agroecological characteristics. In the case of the former, transferring land and capital equipment to a farm enterprise with superior capabilities would attenuate the negative effects of enhanced appropriability on food supply and prices.

Given the findings of the empirical research in developing countries in chapter 5, a specific setting of interest would be one in which a private innovator competes with a public research organization, which may have a different objective function, such as to maximize diffusion in addition to innovation. There are some indications, as suggested in the recent studies by Graff et al. (2009) and Lei et al. (2009) discussed in chapter 2 that policy makers and other stakeholders should pay attention to the risk of an anticommons in agricultural biotechnology. The private sector has assumed a stronger role in investing in agricultural research and technology development which has previously largely been undertaken by public organizations. Understanding the short and long term effects of the increasing use of various proprietary rights in agricultural research by this array of actors is relevant from a food security perspective.

Along similar lines, a relatively neglected area of research has concerned how the availability and use of IPRs affects the direction that R&D programs take. This was indeed one of the principal conclusions of the review presented in chapter 2. For instance, the recent innovation pathway of genetic modification of crops for insect resistance and herbicide tolerance has delivered demonstrable economic, environmental, and social benefits (see, for example, Areal et al., 2012), but other innovation pathways might have dominated under different policies. In particular, the introduction of patent protection for genetic constructs may have directed private research efforts to pursue this innovation pathway given the legal restrictions then available on the saving of seed by farmers. Even though consumer and societal acceptance of genetic modification techniques has been much less forthcoming in Europe, it is plausible that the developments in North America have had a considerable influence on innovation pathways pursued in Europe. Any empirical research in this area will require improvements in metrics by which the direction of breeding research can be measured. In this regard, plant breeding also needs to be seen within the broader context of innovation in agricultural systems, which comprises many more elements than the development of new crop varieties.

Concerning the analysis of the effects of PVPs on trade, it may be very difficult to advance understanding until trade data can be complemented with data on national level investment in seed breeding and production by the private sector. In addition, a better empirical understanding of the amount of seed production (multiplication) and the size of national seed markets would permit an assessment of the effects of IPRs on both trade and investment. This could involve the use of data on varietal registration to complement that on varietal protection, as in the recent historical analysis of the US rose breeding sector by Moser and Rhode (2011). More ambitiously, this approach could be complemented with data on licensing of PVP, so that all three channels of international technology transfer could be covered. Given the differing nature of appropriability issues between different crop species, a more disaggregated analysis can be expected to yield more refined insights. For example, it might be expected that PVP is less important for stimulating trade in crops that have generally been hybridized (e.g. maize, certain vegetables) relative to those that are self-fertilizing (e.g. wheat, soybean) or vegetatively-propagated (e.g. potatoes). Such differences have certainly been suggested for the effect of PVP on investment (see, for example, Alston and Venner, 2002). The analysis in chapter 4 indicates there are different patterns of trade between these crops, even if it is difficult to see a possible effect from PVP (in the form of UPOV membership) from a casual inspection of the data. A quantitative analysis of separate crop species would, in some instances, also allow the inclusion of other variables of interest that are collected at the crop level and which might be expected to have useful explanatory power. One example is the area devoted to cultivation which could be used to make estimates of the size of domestic seed markets; such calculations cannot take place for aggregated crop species due to basic differences in cultivation practices, biological characteristics and seeding rates.

Theory is relatively well developed on the likely impacts of IPRs in general. Most of the existing literature assumes that governments can choose to implement rights such as PVP in a relatively efficient manner (an assumption also made in chapter 3 of the current thesis). The findings of the empirical analysis indicate though that countries face administrative and technical difficulties in implementing an effective PVP system, and such difficulties are not exclusively a matter of political will or commitment as often portrayed in political discussions. More attention could be devoted to understanding the factors influencing the evolution and development of new rights and responsibilities in such a context. This calls for a more comprehensive theory of changing property rights, along the lines of that initiated by Demsetz (2002, 2008), to include IPRs, although the extent to which IPRs should be considered property rights is a matter of debate, at least in the legal literature (Bessen and Meurer, 2008a; Smith, 2007).

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Summary

Seed is one of the most important inputs in agricultural crop production. The genetic code of seed sets the potential frontier of production, in terms of quantity and quality. The knowledgeable use of all other inputs, including land, labour, capital, fertilizers and pesticides, will determine how much of the potential embodied in the seed is realised.

Seed has been produced on-farm since almost the beginning of agriculture, with farmers selecting and maintaining seeds of their crops for sowing next season and exchange with other farmers. The innovative process in plant breeding consists of developing new varieties of crop species that exhibit characteristics which are of interest to either farmers (for example pest resistance, higher yield potential) or to consumers (for example, enhanced flavours, colours, or preservation qualities, or new forms such as in ornamental plants). In this respect, the breeding of new plants constitutes in some cases a process innovation for crop production, and in others, a product innovation.

Agricultural plants are self-reproducing. This rather obvious biological fact is the reason why it can be difficult for plant breeders to appropriate the results of their innovative efforts. Indeed, the very purpose to which seed is put, crop production, results in multiplication of the product. Thus, imitation of the product is fairly easy, and relatively easy to incorporate into farming operations.

Seed is the physical embodiment of the invention of the plant breeder. Plant varieties thus constitute a special form of innovation, and an assessment of intellectual property right (IPR) systems needs to take this into account. This thesis concentrates on IPRs but breeders do have a number of means by which they can capture part of the benefits from the cultivation of their new variety, rather than these falling into to public domain.

During the 20th century, the commercialization of agricultural genetic inputs led to the creation of new intellectual property (IP) instruments, including plant patents in the US in 1930 (for asexually reproduced – or vegetatively-propagated – species, other than potatoes and edible tubers) and then the later emergence in Europe of plant varietal protection (PVP), also referred to as plant breeder's rights (PBR), in Europe. This new form of protection, sometimes described as a combination of copyright and patent protection, was gradually adopted by most industrialized countries. International harmonization led to the International Union for the Protection of New Varieties of Plants (UPOV; Union Internationale pour la Protection des Obtentions Végétales) in 1961. The scope of UPOV protection, both in terms of species coverage and also the rights conferred, was extended in revisions introduced in 1978 and 1991. One of the most important changes in the 1991 Act are further restrictions on the

rights of farmers to save, re-use, exchange and possibly sell seed from a harvested crop that was sown with seed protected by PVP. Restrictions on this "farmer's privilege" have also taken place as technological developments in the area of biotechnology induced the introduction of utility patents in the plant breeding sector, starting in the US in the 1980s.

The overarching question from an economic or policy perspective is how IP policy can best drive innovation as opposed to inhibiting or skewing its advance. IP policy is concerned with the configuration of both rights and responsibilities between farmers, seed companies, public research institutions and governments. In other words, what is both the form and scope of protection that countries should offer? And should all countries offer the same scope of protection? This question is one that is still very relevant for many emerging and developing countries and is at the core of continuing international discussions and negotiations concerning the Agreement on Trade-Related Aspects of Intellectual Property (TRIPS) of the World Trade Organization (WTO).

This thesis brings together four separate papers to explore and inform such policy questions. One is a comprehensive review of literature on IPRs in the agricultural plant breeding sector and the other three are research papers consisting of one theoretical analysis building on a stream of literature in industrial organization, and two distinct empirical analyses, one quantitative and the other qualitative. The papers are not intended to constitute a systematic progression from theoretical development to its empirical verification. Rather they provide separate analyses that illuminate theoretical or empirical aspects of the general policy question concerning the scope of IPRs. The papers are united by their attention to international aspects of IPR policy, in particular the interests and experiences of emerging economies and developing countries.

A comprehensive review of the economic literature on IPRs in the agricultural biotechnology and plant breeding sector is provided by chapter 2. Various IPRs, including plant patents, PVP and utility patents, have been introduced during the course of the twentieth century in many countries. Much of the research and analysis in this area has concentrated on how policy can improve the system of IPRs in order to maximize the rate of innovation. There are some indications that the growth in use and scope of IPRs, particularly utility patents, may have a detrimental effect on innovation by increasing the uncertainty and transaction costs in undertaking research in this sector. In addition, a relatively neglected area of research has concerned how the availability and use of IPRs has affected the nature and direction of R&D efforts in plant breeding, as part of agricultural research in general. There are relatively few studies that do not focus on major grains and oilseed crops, where innovations recently have been dominated by the use of genetic modification techniques. Finally, it appears that much might be learned from increasing research into licensing, exchange, enforcement and litigation of IPRs in this area.

In chapter 3, an analysis of the tradeoffs involved in the extent of IP protection offered for an intermediate good is presented, in an attempt to better represent innovation incentives in the farm sector. A theoretical model of vertical product differentiation with a monopolist innovator supplying an intermediate good to heterogeneous producers is developed. Firms, in this case farm enterprises, use the intermediate good to produce a homogeneous final good. This provides a relatively simple approach for assessing the effects changes in appropriability on the incentive to innovate.

The model highlights how heterogeneity among farms leads to differing interests. More productive farms may benefit from a higher level of appropriability as they are able to profit more from the resulting higher level of innovation and quality in the intermediate good. Less productive farms, in contrast, would benefit from a more moderate level of appropriability so that they could afford the intermediate good, including possibly pirated copies. In this kind of model, farms definitely have an interest in some positive level of appropriability, as otherwise there would be no investment at all in innovation. Consumers, for their part, would benefit from lower prices, as the final good is homogenous, and this can be achieved with a moderate level of appropriability, thus maximizing the number of farms able to produce. This result may be contingent on the situation analyzed here, in which seed consitutes a process innovation enhancing farm productivity, as opposed to a product innovation with direct benefits for consumers.

By explicitly modeling the intermediate good nature of seed, the analysis introduces an interdependence between farms who all compete in the production of the final good. The output price that farms receive depends on the number of them that are able to produce. This in turn is influenced by the combination of quality and price of the seed input. In this model, the monopolist anticipates these effects and selects quality and price to maximize profit. Higher appropriability encourages higher quality but also higher prices for seed, and some farms are not able to produce. The aggregate profits of the farm sector may well be increased, along with those of the innovator. But less productive farms and consumers will be disadvantaged. This provides an explanation for the observed alignment of interests in policy discussions concerning IPRs, with seed companies finding allies for stronger IPRs in more efficient, large-scale farms, who are opposed by small-scale farms with some support from consumer groups or civil society organizations.

Extending the analysis to a setting involving two countries, North and South, confirms earlier results using different types of models. In the absence of domestic innovative capacity, both farms and consumers in the South benefit most from minimal appropriability as diffusion of the seed is maximized at lowest cost by the possibility of pirating. When trade in the final farm product is introduced, farms in the North find themselves competing with those in the South, and the former will have an interest in seeing appropriability increased in the South, in order to reduce this competition.

Following this theoretical analysis, chapter 4 undertakes an empirical analysis of international trade in agricultural seeds and does not find any significant relationship between the existence or introduction of PVP in a country and its imports of seed from 10 EU exporting countries or the US. Earlier work has considered exports of seeds from only the US and for a shorter period of time, whereas the 10 principal exporters among the EU, taken together (Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, the UK), are an even larger exporter, with exports in 2007 of US$ 1,978 million versus US$ 765 million for the US. The analysis employed quantile regression techniques, recently extended to dynamic models with specific effects, to address evidence of heterogeneity among importing countries in the extent to which seed imports are explained by various factors. The analysis here, using a more comprehensive approach and dataset, is consistent with the earlier result.

These results suggest two possible explanations. First, other factors, including tariffs, specific regulations (such as varietal testing or sanitary or phytosanitary regulations) may play a more important role than IPRs in affecting trade in this sector. Such additional factors may not have been adequately captured in the analysis. Relatedly, for certain grain and oilseeds crops, the patterns of trade may be affected more by the growing share of genetically modified crops, and their specific trade frictions related to biosafety regulations and consumer concerns. This does not necessarily imply that PVP is not important; it may play more of a role in stimulating investment, either domestic or foreign in origin, rather than influencing trade. A second explanation is that the implementation of PVP in many countries has still not led to a system of IPRs that are sufficiently effective to provide incentives for trade and perhaps investment.

Then chapter 5 reports on an empirical analysis of five country experiences (China, Colombia, India, Kenya and Uganda) with implementing IPRs, particularly PVP. The study uses qualitative methods to determine how different stakeholders in these countries are responding to this policy change. Responses were collected through a series of interviews primarily with private sector seed companies and public sector agricultural research organizations. The results indicate that the effectiveness of PVP is not yet very high, even in countries with some longer experience, thus supporting the second explanation above. In general, weak IPRs reflect the institutional capacity of public agencies in such countries, as these are responsible for establishing a system for granting rights. In many countries, plant breeding companies are cautious to submit varieties for testing for the criteria of distinctness, uniformity and stability (DUS) if they have concerns about the security of the testing procedure, including the integrity of the officials involved. New varieties could fall into competitors' hands before they have even been granted PVP protection. In addition, breeders require some degree of confidence in the specific legal channels by which alleged infractions of PVP titles may be pursued. In general, these findings provide some support to the second explanation that PVP has not affected international trade in seeds due to the PVP systems in developing countries still being insufficiently effective.

The findings also indicate that PVP is likely to be more effective as a means to prevent unauthorized multiplication and commercial sale of seed of protected varieties, than as a means to limit seed saving by farmers. The costs of enforcing the latter practice are generally too high in developing countries and the issue is highly controversial. One reason for this is that limiting seed saving may have consequences for food security at a local level. PVP might begin to play a role in ensuring transparency and removing information asymmetry in seed markets, which would also contribute to enhanced competition and thus innovation among breeding companies.

Various policy implications emerge from the results in the thesis. The theoretical model highlights that broader scope or enforceability of IPRs may increase innovation but a policy of maximizing innovation can disproportionately affect different groups of producers and consumers. The findings here suggest that not all producers benefit from increased innovation, nor do all consumers. Relatedly, the analysis has highlighted how IPR policy, as a component of innovation policy, may need to take into account the special nature of food as an economic good constituting a basic human need. Increasing innovative efforts and outcomes, through broader IPRs, might not necessarily improve the availability of food for all consumers, nor access to it. The limitations of the analysis in the thesis caution strongly though against an unequivocal position on this issue.

The case for different levels of appropriability provides support to the position of maintaining existing flexibilities in the TRIPS Agreement. One of the most relevant is the ability of countries to provide for protection of plant varieties through PVP and/or patents (Article 27.3(b)). The interpretation of what constitutes "effective" protection in this case could also provide room for flexibility in the scope of PVP, particularly as concerns the possibility for allowing the granting of a farmer's privilege.

The empirical analysis of experiences in developing countries from implementing these obligations also provides support for maintaining an international regime that permits flexibilities in implementing PVP. The results support a continued extension of the deadline for least developed countries to comply with Article 27.3(b), since this seems to be providing little immediate benefit in many cases, but does place demands on scarce administrative and institutional capacity in such countries. The results from the five case study countries support the recommendation that TRIPS obligations should not include strict requirements regarding seed saving and the elimination of the farmer's privilege.

There are many remaining questions concerning the optimal IPR policy for the plant breeding and crop genetics sector. The understanding of some of these questions could benefit from further development of theoretical models to support reasoned insights of likely impacts of proposed policies, particularly given the continued push by some seed companies for broader IP protection for seeds. In terms of theoretical modeling, further work could usefully explore the outcomes of strategic interaction between competing breeders, including a generalized formulation of final demand and possibly also exploring whether the distribution of farms plays a role. Given the findings of the empirical research in developing countries, a specific setting of interest would be one in which a private innovator competes with a public research organization, which may may have a different objective function, such as to maximize diffusion in addition to innovation.

At the same time, there are clearly a number of issues in which empirical research is necessary to understand the relative importance of the various causal mechanisms seemingly at work in IPRs. Concerning the analysis of the effects of PVPs on trade, it may be very difficult to advance understanding until trade data can be complemented with data on national level investment in seed breeding and production by the private sector. In addition, a better empirical understanding of the amount of seed production (multiplication) and the size of national seed markets would permit an assessment of the effects of IPRs on both trade and investment. The findings of the detailed empirical analysis in five countries indicate though that countries face administrative and technical difficulties in implementing an effective PVP system, and such difficulties are not exclusively a matter of political will or commitment as often portrayed in political discussions. This suggests more attention could be devoted to understanding the factors influencing the evolution and development of new rights and responsibilities in such a context.

Samenvatting

Zaaizaad is een van de meest belangrijke inputs in de landbouw. De genetische code van zaaizaad bepaalt de potentiele productiegrens, in termen van kwantiteit en kwaliteit. Het goed geïnformeerde gebruik van andere inputs, inclusief land, arbeid, kapitaal, mest en bestrijdingsmiddelen, bepaalt de mate waarin de mogelijkheden geboden door het zaaizaad worden gerealiseerd.

Al vanaf het begin van de landbouw werd zaaizaad geproduceerd door boerenbedrijven zelf, waardoor boeren zaaizaad selecteerden en bewaarden om te zaaien in het volgende seizoen of om uit te wisselen met andere boeren. Het innovatieve procédé van plantenveredeling bestaat uit het ontwikkelen van nieuwe variëteiten van gewassoorten met eigenschappen die van belang zijn voor andere boeren (bijv. resistentie tegen plagen, hogere potentiële opbrengst) of consumenten (bijv. verbeterde smaak, kleuren, of conserveringsmogelijkheden, of nieuwe vormen zoals bij sierplanten). In dit opzicht vormt het veredelen van nieuwe planten in sommige gevallen een procesinnovatie voor de gewasteelt, en in andere gevallen een productinnovatie.

Landbouwgewassen reproduceren zichzelf. Dit is de reden waarom plantenveredelaars moeite hebben om de baten te oogsten van hun inspanningen in innovatie. Het doel van het gebruik van zaaizaad, gewasteelt, resulteert in vermeerdering van het product. Dus imitatie van het product is redelijk makkelijk, en ook makkelijk om te realiseren op het boerenbedrijf.

Zaaizaad is de fysieke uitdrukking van de uitvinding van een plantenveredelaar. Plantenvariëteiten vormen een bijzonder type van innovatie, en alle analyses van intellectuele eigendomsrechten (IE) systemen dienen hier rekening mee te houden. Dit proefschrift concentreert zich op IE, maar veredelaars hebben een aantal andere tactieken teneinde zich een deel van de baten van de teelt van nieuwe variëteiten toe te eigenen, en te voorkomen dat deze in het publieke domein terecht komen.

In de twintigste eeuw heeft de commercialisering van genetische inputs in de landbouw ertoe geleid dat nieuwe instrumenten van intellectueel eigendom zijn ontstaan. Dit betreft onder andere plantenoctrooien in de VS in 1930 (voor geslachtloos gereproduceerde – of vegetatief vermeerderde – gewassoorten, uitgezonderd aardappelen en eetbare wortelknollen) en de ontwikkeling in Europa van de bescherming van plantenvariëteiten, ook kwekersrechten genoemd (KR). Deze nieuwe vorm van bescherming, soms beschreven als een combinatie van auteursrecht en octrooi, werd geleidelijk in gebruik genomen door het merendeel van de geïndustrialiseerde landen. Internationale harmonisatie heeft in 1961 geleid tot de oprichting van het International Union for the Protection of New Varieties of Plants (UPOV). De omvang van bescherming onder UPOV werd uitgebreid in 1978 en 1991 toen het verdrag herzien werd. Een van de belangrijkste veranderingen in het verdrag van 1991 betreft omvangrijker beperkingen op de rechten van telers om geoogst zaad te bewaren, opnieuw te zaaien, of uit te wisselen. Beperkingen op deze uitzondering voor telers hebben plaatsgevonden terwijl technologische ontwikkelingen in de biotechnologie hebben geleidt tot de invoering van bescherming van uitvindingen van de plantenveredeling door octrooien, eerst in de VS in de jaren tachtig.

De overkoepelende vraag vanuit een economisch- of beleidsperspectief is hoe het IE-beleid innovatie het best kan ondersteunen en stimuleren, in plaats van deze te beperken. Het IE-beleid betreft de samenstelling van rechten en verantwoordelijkheden onder telers, zaaizaadbedrijven, publieke onderzoeksinstellingen en overheid. Met andere woorden, welke vorm en omvang van bescherming dient te worden geboden? En moeten alle landen dezelfde bescherming bieden? Deze vraag is nog steeds relevant voor meerdere ontwikkelingslanden, en vormt de basis van lopende internationale besprekingen en onderhandelingen ten aanzien van de Agreement on Trade-Related Aspects of Intellectual Property (het TRIPS verdrag) bij de Wereldhandelsorganisatie (WTO).

Dit proefschrift staat uit vier afzonderlijke papers met als doel deze beleidsvragen te onderzoeken en beleidsmakers te informeren. Het eerste paper bestaat uit een overzicht van de literatuur over IE in plantenveredeling, en de andere drie bestaan uit een theoretische analyse (voortbouwend op een stroom van literatuur in de industriële economie), en twee aparte empirische analyses (kwantitatief en kwalitatief). Deze hoofdstukken bieden afzonderlijke analyses die theoretische en empirische aspecten behandelen van de overkoepelende beleidsvraag betreffende de omvang van IE. De hoofdstukken zijn logisch verbonden door de aandacht voor internationale aspecten van het IE-beleid, vooral de belangen en ervaringen van opkomende economieën en ontwikkelingslanden.

Het tweede hoofdstuk bestaat uit een overzicht van de economische literatuur over IE in de landbouw biotechnologie en plantenveredeling. Verschillende IE, inclusief plantenoctrooien, het kwekersrecht en gewone octrooien, werden ingevoerd in de loop van de twintigste eeuw in meerdere landen. Een groot deel van het onderzoek op dit gebied heeft zich geconcentreerd op het vraagstuk hoe beleid het IE-systeem kan verbeteren om innovatie te maximaliseren. Er bestaan aanwijzingen dat het toenemende gebruik en omvang van IE, vooral octrooien, nadelige effecten op innovatie hebben als gevolg van toenemende onzekerheid en transactiekosten in het onderzoek in deze sector. Een relatief onderbelicht gebied van onderzoek betreft het effect van IE op het type en richting van dit onderzoek, als onderdeel van landbouwkundig onderzoek in het algemeen. Er bestaat weinig onderzoek dat zich niet richt op de belangrijke graangewassen en oliezaden, waarbij recente innovaties gedomineerd worden door het gebruik van genetische modificatie. Ten slotte lijkt het erop dat er veel te leren is door het doen van meer onderzoek naar licenties, uitwisseling, handhaving en rechtszaken ten opzichte van IE op dit gebied.

Het derde hoofdstuk analyseert de afwegingen over de omvang van bescherming van intellectuele eigendom in het geval van productiegoederen, in een poging te komen tot een betere representatie van innovatie in de landbouwsector. Een theoretisch model van verticale productdifferentiatie wordt opgesteld met een monopolistisch innovator die een productiegoed levert aan heterogene producenten. Die bedrijven, in dit geval landbouwbedrijven, gebruiken dit product om een homogeen consumptiegoed te produceren. Dit levert een relatief eenvoudige manier op om de effecten te bestuderen van veranderingen in de mate waarin een innovator zich de baten van zijn uitvinding kan toeeigenen op de prikkels tot innovatie.

Het model illustreert hoe heterogeniteit tussen boerenbedrijven aanleiding kan zijn tot conflicterende belangen. Meer productieve bedrijven, die meer kunnen profiteren van betere productiegoederen, hebben baat bij een hoger niveau van toewijzing van baten aan de innovator. Maar minder productieve bedrijven profiteren juist van een lager niveau van toewijzing van baten aan de innovator. Dit stelt hen in staat de kosten van het product te betalen, of het product te kopiëren. In deze opzet hebben boerenbedrijven belang bij een positief niveau van toewijzing, omdat er anders geen investering in innovatie plaatsvinden. Op hun beurt hebben consumenten baat bij lagere prijzen, omdat het product dat zij kopen homogeen is. Dit wordt bereikt met een matig niveau van toewijzing van de baten aan de innovator, waardoor een maximaal aantal boerenbedrijven gaan produceren. Dit resultaat hangt af van de specifieke omstandigheden van het model, waarin zaaizaad een procesinnovatie is die de productiviteit van boerenbedrijven verhoogt, in plaats van een productinnovatie met directe baten voor consumenten.

Door het expliciet modeleren van het karakter van zaaizaad als een soort van productiegoed wordt een afhankelijkheid geïntroduceerd tussen boerenbedrijven, die allemaal met elkaar concurreren in het produceren voor de markt. De prijs die boerenbedrijven ontvangen hangt af van het aantal bedrijven dat produceert. Dit wordt op zijn beurt bepaald door de kwaliteit en prijs van het zaaizaad dat boerenbedrijven kopen. In het model anticipeert de monopolist op al deze effecten, en selecteert het de combinatie van kwaliteit en prijs die de winst maximaliseren. Een grotere mate van toewijzing van baten aan de monopolist stimuleert betere kwaliteit, maar leidt tegelijkertijd tot hogere prijzen voor zaaizaad. Dit kan betekenen dat sommige boerenbedrijven niet produceren. De totale winst van alle boerenbedrijven samen kan dan wel toenemen, alsmede die van de innovator, maar minder productieve boerenbedrijven verliezen en ook consumenten zijn slechter af. Dit verklaart de botsende belangen bij beleidsdiscussies met betrekking tot IE, waarbij zaaizaadbedrijven samen optrekken met meer productieve boerenbedrijven voor verder-reikende IE terwijl kleinere bedrijven, gesteund door consumentenorganisaties of NGO's, het tegenovergestelde betogen.

Een uitbreiding van de analyse naar een opzet met twee landen, Noord en Zuid, geeft een bevestiging van eerdere resultaten gebaseerd op andere soorten modellen. Bij het ontbreken van binnenlands innovatievermogen hebben zowel boerenbedrijven als consumenten in het Zuiden baat bij een minimaal niveau van toewijzing van baten aan de innovator. Dit komt doordat verspreiding en gebruik van het zaaizaad gemaximaliseerd wordt tegen lagere kosten door de mogelijkheid om deze te kopiëren zonder toestemming. Wanneer internationale handel in het voedselproduct mogelijk wordt, moeten boerenbedrijven in het Noorden concurreren tegen bedrijven uit het Zuiden.

De eersten hebben dan belang bij dat een grotere toewijzing van baten in het Zuiden aan de innovator omdat dit de concurrentie kan verzachten.

Het vierde hoofdstuk is gebaseerd op een empirische analyse van de internationale handel in zaaizaad, en vindt geen statistisch aantoonbare verhouding tussen het bestaan of de invoering van het kwekersrecht in een land en de invoer van zaaizaad uit 10 exporterende EU landen of de VS. Voorafgaand onderzoek betrof alleen de uitvoer van zaaizaad uit de VS over een kortere periode, terwijl de 10 grootste exporterende landen van de EU bij elkaar (België, Denenmark, Frankrijk, Duitsland, Griekenland, Italië, Nederland, Portugal, Spanje en de VK), meer exporteren met een waarde van 1,978 miljoen dollars in 2007 ten opzichte van 765 miljoen dollars voor de VS. De analyse gebruikt technieken van kwantiel regressie, recentelijk uitgebreid voor dynamische modellen met 'fixed effects', als een manier om heterogeniteit tussen importerende landen mee te nemen (in de mate waarin de invoer van zaaizaad verklaard wordt door verschillende factoren). Op basis van een methodologie die meer robuust is en gebaseerd op een grotere dataset, vinden we dat de resultaten consistent zijn met eerdere resultaten.

Deze resultaten suggereren twee mogelijke verklaringen. Ten eerste, het kan zijn dat andere factoren, inclusief invoertarieven, specifieke reguleringen (zoals sanitaire of fytosanitaire maatregelen) een belangrijkere rol spelendan IE bij het beïnvloeden van de internationale handel in deze sector. Zulke additionele factoren zijn mogelijk onvoldoende meegenomen in de analyse. Bijvoorbeeld, misschien hebben het toenemende aandeel van genetische gemodificeerde gewassen en bijbehorende maatregelen ten opzichte van biosafety en consumentenvraagstukken meer invloed op handel. Dit hoeft niet te betekenen dat het kwekersrecht onbelangrijk is. Dit kan bijvoorbeeld een grotere rol spelen bij het stimuleren van (buitenlandse) investeringen, in plaats van invloed hebben op de handel. Een tweede verklaring is dat de invoering van het kwekersrecht in meerdere landen nog niet geleidt heeft tot een systeem van IE dat effectief genoeg is om handel en investering te stimuleren.

Het vijfde hoofdstuk bespreekt een empirische analyse van de ervaringen in vijf landen (China, Colombia, India, Kenia en Oeganda) met de invoering van IE, en dan vooral het kwekersrecht. Dit onderzoek gebruikt kwalitatieve methodes om te bepalen hoe verschillende actoren in deze landen op deze beleidsverandering hebben gereageerd. Antwoorden zijn verzameld door middel van een reeks interviews met zaaizaadbedrijven en publieke landbouwkundige onderzoeksinstellingen. De resultaten geven aan dat de effectiviteit van het kwekersrecht nog niet zo groot is, zelfs in landen met meerdere jaren ervaring. Dit onderbouwt de tweede verklaring hierboven (hoofdstuk 4). In het algemeen is zwakke IE een teken van de institutionele capaciteit van publieke instellingen. In meerdere landen zijn veredelingsbedrijven voorzichtig bij het indienen van exemplaren van nieuwe variëteiten voor het testen van onderscheiding, uniformiteit en stabiliteit (DUS) omdat zij zich zorgen maken om het waarborgen tegen ongewenste verdwijning van dit materiaal. Deze zorgen betreffen ook de integriteit van het verantwoordelijke personeel. Zo zouden nieuwe variëteiten in handen kunnen komen van concurrenten voordat een bescherming door kwekersrecht toegekend is. Daarnaast hebben veredelingsbedrijven een mate van zekerheid nodig ten opzichte van de juridische kanalen die gebruikt kunnen worden om verdachte inbreuk op het kwekersrecht tegen te gaan. Deze bevindingen suggereren dat het kwekersrecht geen effect heeft gehad op de internationale handel in zaaizaad omdat deze IE systemen in ontwikkelingslanden nog onvoldoende effectief zijn.

De resultaten geven ook aan dat kwekersrecht waarschijnlijk effectiever zal zijn als manier om onbevoegde vermeerdering en verkoop van zaaizaad van beschermde variëteiten te voorkomen, dan als manier om het bewaren van zaaizaad door boeren te beperken. Voor deze laatste kwestie zijn de kosten van het handhaven meestal te hoog in ontwikkelingslanden. Bovendien is de kwestie zeer controversieel. Een reden hiervoor is dat het beperken van het bewaren van zaaizaad gevolgen kan hebben voor voedselzekerheid op lokaal niveau. Het kwekersrecht speelt wel een rol bij het verzekeren van transparantie en het beperken van informatieongelijkheid in zaaizaadmarkten. Dit zou kunnen bijdragen aan scherpere concurrentie en dus innovatie onder veredelingsbedrijven.

Verschillende beleidsimplicaties kunnen worden afgeleid uit de resultaten van dit proefschrift. Het theoretische model illustreert dat een betere bescherming van IE innovatie kan bevorderen, maar een beleidsdoel dat innovatie maximaliseert kan ongelijke effecten hebben op verschillende groepen van producenten en consumenten. De resultaten suggereren dat niet iedereen baat heeft bij een toename van innovatie. De analyse heeft ook geïllustreerd hoe het IE-beleid, als onderdeel van innovatiebeleid, rekening moet houden met het bijzondere karakter van voedsel als eerste levensbehoefte voor de mens. Een toename van innovatie , als gevolg van omvangrijker IE, leidt niet noodzakelijk tot een toename van de beschikbaarheid en toegankelijkheid van voedsel voor alle consumenten. Niettemin is het moeilijk om ondubbelzinnige conclusies te trekken op dit punt.

De analyse van de mate van bescherming ondersteunt ook het standpunt dat de flexibiliteit ingebouwd in het TRIPS verdrag bewaard moet worden. Een relevant voorbeeld hiervan is de mogelijkheid voor landen om bescherming van plantenvariëteiten aan te bieden door middel van het kwekersrecht en niet noodzakelijk door middel van octrooien (Artikel 27.3(b)). Bovendien kan de interpretatie in het verdrag van wat wordt beschouwd als “effectieve” bescherming ook ruimte bieden ten opzichte van de omvang van het KR. Effectief bescherming kan namelijk wel consistent zijn met het toekennen van de rechten van boeren om zaaizaad te bewaren.

Een pleidooi voor flexibiliteit in het internationale systeem van KR volgt ook uit de empirische analyse van ervaringen in ontwikkelingslanden die deze verplichtingen hebben ingevoerd. De resultaten ondersteunen een verlenging van de vervaldatum voor de minst ontwikkelde landen om te voldoen aan de verplichtingen van Artikel 27.3(b), omdat er weinig bewijs is dat de bijbehorende baten opwegen tegen de kosten. Er wordt wel beslag gelegd op schaarse administratieve en institutionele capaciteit in deze landen. De resultaten van de vijf casus landen steunen een aanbeveling dat verplichtingen onder TRIPS geen strenge eisen moeten stellen met betrekking tot het bewaren van zaaizaad en voorrechten voor boeren.

Meerdere vragen blijven bestaan over het optimale IE-beleid voor de plantenveredeling en biotechnologie sector. Er moet worden gewerkt aan de verdere ontwikkeling van theoretische modellen als basis voor inzichten in de mogelijk uitkomsten van beleidsvoorstellen. Dit is des te belangrijker gezien de druk voor omvangrijker IE vanuit sommige zaaizaadbedrijven. Theoretisch vervolgonderzoek zou de strategische interactie tussen veredelaars moeten analyseren, gegeven een bepaalde vraag naar voedsel, en mogelijk ook met aandacht voor de rol die verdeling van boerenbedrijven speelt in de afwegingen. De resultaten van het empirische onderzoek in ontwikkelingslanden suggereren dat het van belang is de case te bekijken waarbij een innoverend bedrijf concurreert tegen een publieke onderzoeksinstelling. Een dergelijke instelling heeft niet winstmaximalisatie tot doel, maar bijvoorbeeld het maximaliseren van de verspreiding van innovaties.

Tegelijkertijd zijn er een aantal vraagstukken waarvoor meer empirische onderzoek nodig is om de verschillende effecten van IE beter te begrijpen. Ten opzichte van de verhouding tussen het KR en internationale handel is het van belang gegevens over investeringen door het bedrijfsleven in veredeling en vermeerdering te verzamelen. Ook stellen betere inzichten in de omvang van vermeerdering en van nationale zaaizaadmarkten onderzoekers in staat te kijken naar de gevolgen van IE op handel en investeringen. De gedetailleerde resultaten van de vijf landen geven aan dat landen administratieve en technische moeilijkheden ondervinden bij het invoeren en opbouwen van een effectief KR-systeem. Deze moeilijkheden zijn niet alleen een kwestie van politieke wil of inspanning, zoals soms wordt gesuggereerd in beleidsdiscussies. We moeten meer aandacht besteden aan de factoren die de ontwikkeling en evolutie van deze rechten en verantwoordelijkheden beïnvloeden.

Curriculum vitae

Derek John Finlayson Eaton was born on 7 November 1965 in Toronto, Ontario, Canada. He studied at the University of Toronto from 1984 to 1989, obtaining a B.Sc. degree in Economics (Quanitative Methods), with a minor in Political Science. He was awarded the Lorne T. Morgan Gold Medal for the leading graduating student in economics. From 1989 to 1990, he studied development studies and administration at the University of Ottawa, obtaining a Postgraduate Diploma in International Development and Co-operation. From 1992 to 1993, he studied at University College London, obtaining a M.Sc. degree in Environmental and Resource Economics (with Distinction).

From 1990 to 1992, he worked as an inter-agency affairs officer in the Office of the Executive Director of the United Nations Environment Programme (UNEP) in Nairobi, Kenya. From 1993 to 1995, he was a research associate with the Environmental Economics Programme at the International Institute for Environment and Development (IIED) in London, UK and employed as a consultant to IIED thereafter until 1997. At IIED he undertook research on the valuation of wild resources and forest goods and services. From 1997 to 1998, he worked as an economist in Food Aid Centre of the Canadian International Development Agency (CIDA) in Ottawa, Canada, where he was responsible for representing Canada to the Consultative Group on International Agricultural Research (CGIAR) and managing contributions to its research centres.

From 1998 to 2009, he was a researcher at the Agricultural Economics Research Institute (LEI) in the Hague, part of the Wageningen University and Research Centre. At LEI, he worked first with the Horticulture Division and later for the International Trade and Development Unit of the Public Issues Division. He coordinated an EC-funded research project on the recycling of urban waste in periurban agriculture in Burkina Faso and Mali. He undertook numerous studies on the economics of genetic resource management and the plant breeding sector, on behalf of the Netherlands government, the Food and Agriculture Organization of the United Nations, the World Bank, business and NGOs. For research on differentiated tariffs and nontariff trade measures linked to animal welfare in meat production, he was awarded LEI's first Vinus Zachariasse Prize for research with greatest policy impact in 2006. In 2003, he began following doctoral courses part-time with the Netherlands Economics Network (NAKE) and also the CentER for Research in Economics and Business at Tilburg University. In 2006, he was admitted as an external PhD candidate to the Mansholt Graduate School (now the Wageningen School of Social Sciences).

From 2009 to 2011, he was employed as a programme officer in the Economics and Trade Branch of the Division of Technology, Industry and Economics of UNEP in

Geneva, Switzerland. He was a co-author of UNEP's commissioned report, *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication* and also oversaw the integrated assessment modeling undertaken for this report.

Since 2012, he holds the position of Executive Director of the Centre for International Environmental Studies (CIES) of the Institute of International and Development Studies (Graduate Institute, Geneva).

Derek J.F. Eaton
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the activity	Department/Institute	Year	ECTS (1=28 hrs)
Project related competences			
T03.92 Economics of technological change (B. Verspagen)	NAKE	2003/4	3
F04.06 Industrial organization (D. Furth, M. Haan, B. Schoonbeek)	NAKE	2004/5	6
UvT Centre Grad. School Econometric Models in Economics (230256)	CentER, Tilburg	2005/6	6
General research related competences			
F04.04 Dynamic macroeconomics (J. Smulders)	NAKE	2004/5	6
T03.46 Optimisation methods in econometrics (J. Magnus)	NAKE	2003/4	3
Mansholt Introductory Course	Mansholt	2007/8	1
" The case for differentiated appropriability in intellectual property rights for plant varieties"	International Consortium on Agricultural Biotechnology Research (ICABR)	2002	1
" Impacts of Strengthened Intellectual Property Rights Regimes on the Plant Breeding Industry in Developing Countries: A Synthesis of Five Case Studies"	ICABR	2005	1
" Should Europe Further Strengthen Intellectual Property for Plant Breeders? An Analysis of Seed Industry Proposals"	European Association of Agricultural Economists (EAAE)	2005	2
" Trade and Intellectual Property Rights in the Agricultural Seed Sector "	EAAE	2008	2
Career related competences/personal development			
European School on New Institutional Economics (ESNIE)	ESNIE	2006	1.5
" Transaction Costs of Tracking and Monitoring the Flow of Agricultural Genetic Resources"	BIOECON Conference Cambridge	2006	1
" The Effects of Strengthened IPR Regimes on the Plant Breeding Sector in Developing Countries "	Internationaal Association of Agricultural Economics (IAAE)	2006	2
" Intellectual Property Rights in Plant Breeding and Biotechnology: a Comparative Institutional Analysis"	Conference of the International Society for New Institutional Economics (ISNIE), Reykjavik	2007	1
"Searching for Trade-Related Aspects of Intellectual Property Rights in the Plant Breeding Sector"	Conference of the Canadian Association of Agricultural Economics (CAAE), Toronto	2009	1
TOTAL			37,5