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TRADE AND INTELLECTUAL PROPERTY RIGHTS IN THE AGRICULTURAL SEED SECTOR

D. EATON

Trade and intellectual property rights in the agricultural seed sector

Derek J.F. Eaton*

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The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) has continued to be fiercely debated between North and South, particularly with respect to its provisions for the agricultural sector. 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). This paper analyzes the effects of the introduction of PBRs in almost 80 importing countries on the value of exports of agricultural seeds and planting material from 10 exporting EU countries, including all principal traditional exporters of seeds, as well as the US. A dynamic penalized fixed effects quantile regression model, based on a general specification for the gravity model for international trade, is estimated using panel data covering 19 years (1989-2007) of export flows in order to assess the effect of International Convention on the Protection of New Varieties of Plants (UPOV) membership on seed imports. Basing inference on the panel bootstrap, we find no significant effect from UPOV membership on seed imports.

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JEL Classification: F13, O34, Q17

1 Introduction

This paper analyzes the effect of intellectual property rights (IPRs) on trade in goods. IPRs entered 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

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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 literature yielding mixed results. Grossman and Lai (2004), building on Grossman and Helpman (1990) and Lai and Qiu (2003), have analyzed 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 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. Agricultural plants are essentially self-reproducing, posing a potential appropriability problem for breeders considering typical investment periods of 10-15 years. Private sector investments in agricultural plant breeding have largely been confined to hybrid varieties, which do not produce seed with the exact same characteristics as the crossing of the two parent varieties. Breeders and seed companies attempt to keep the parental lines secret. For other open-pollinated plants (e.g. wheat, lettuce) or those that reproduce vegetatively (e.g. potatoes) IPR protection is more important. And for hybrids, IPRs can add additional protection, above the in-built physical/biological security that is still vulnerable to being obtained and copied, or even reverse engineered using the tools of modern biotechnology (such as molecular markers).

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[1] 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 paper 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.[2]

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 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

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

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

flows.

The effects of stronger IPRs on seed trade has recently been analyzed 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 paper 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 necessary 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 paper 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.

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).[3] 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.[4] 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.[5] 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.[6]

Data on seed exports from the 10 European countries was extracted from the Eurostat trade database[7] and for the United States, from the US Agricultural Trade Database of the USDA's Foreign Agricultural Service.[8] 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 totaled 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 others 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

[3]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 sub-sample 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.

[4]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.

[5]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.

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

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

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

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.[9]

The value of seed imports for each of the countries from both the US and the EU is presented in figures 1 through 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.[10] 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 asterisk (*) 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 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, but with Argentina in figure 1), with the exception of Brazil where imports from the two sources are of comparable value.

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 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,

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

[10] 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.

Figure 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)

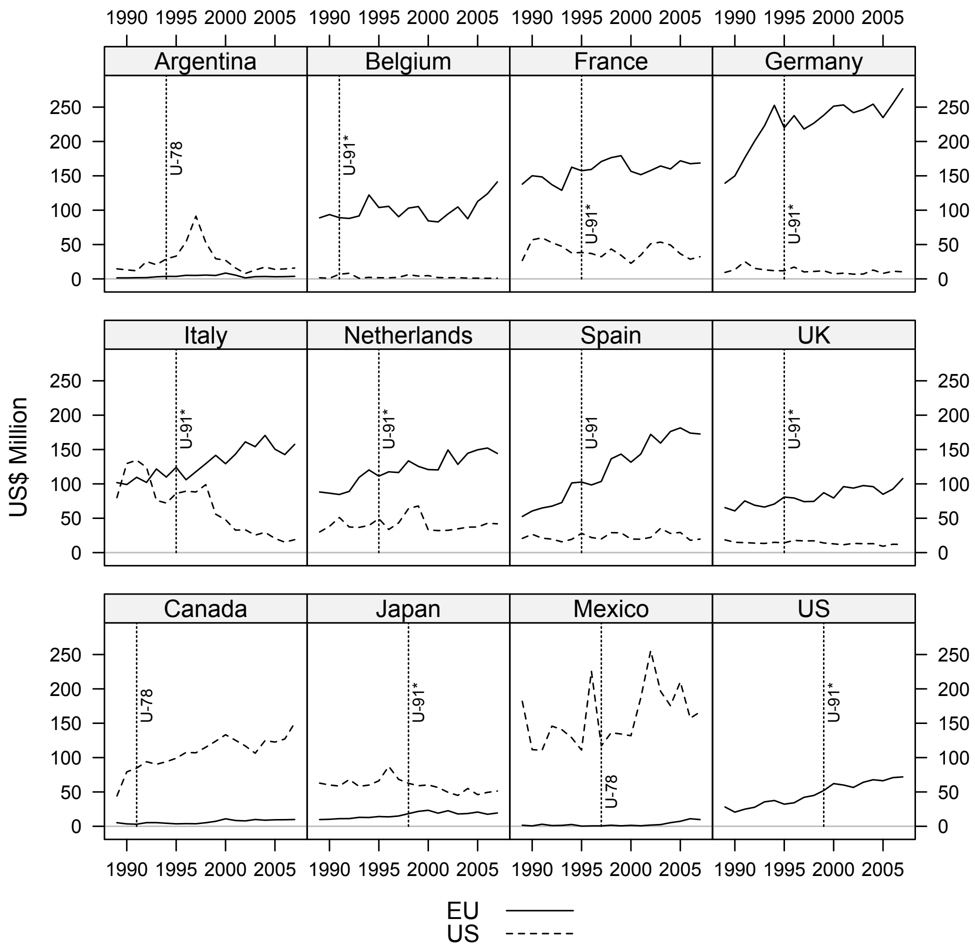


Figure 2: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 2 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

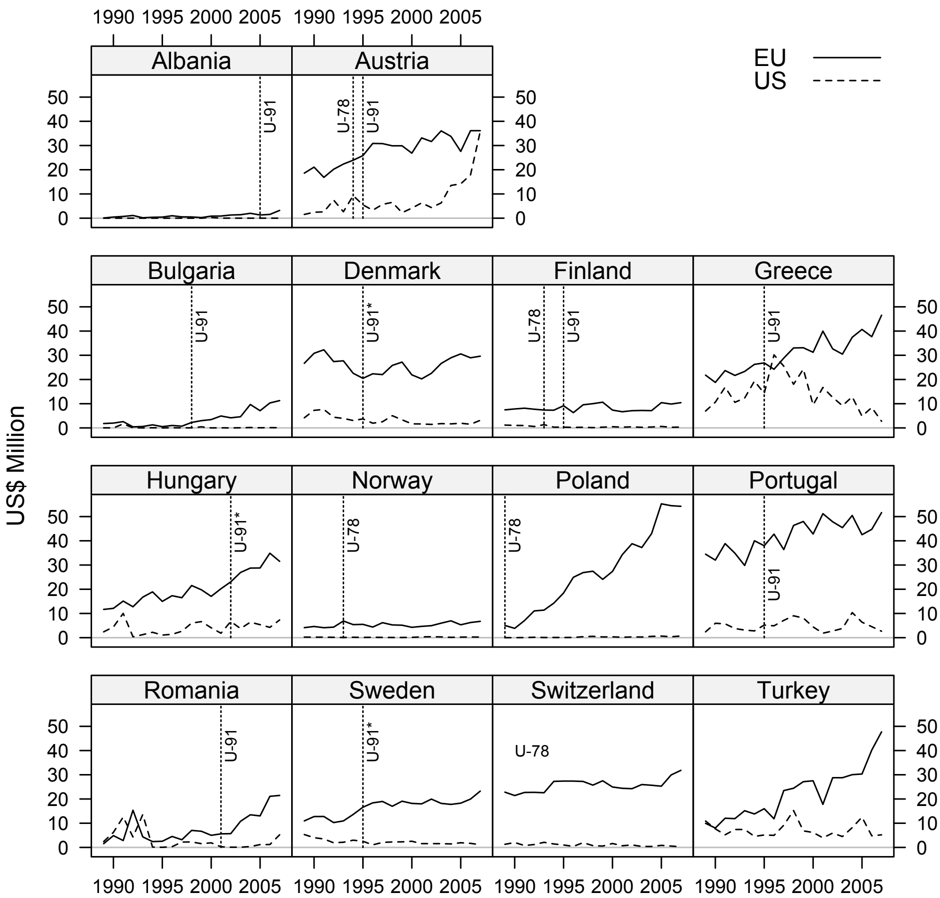


Figure 3: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 3 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

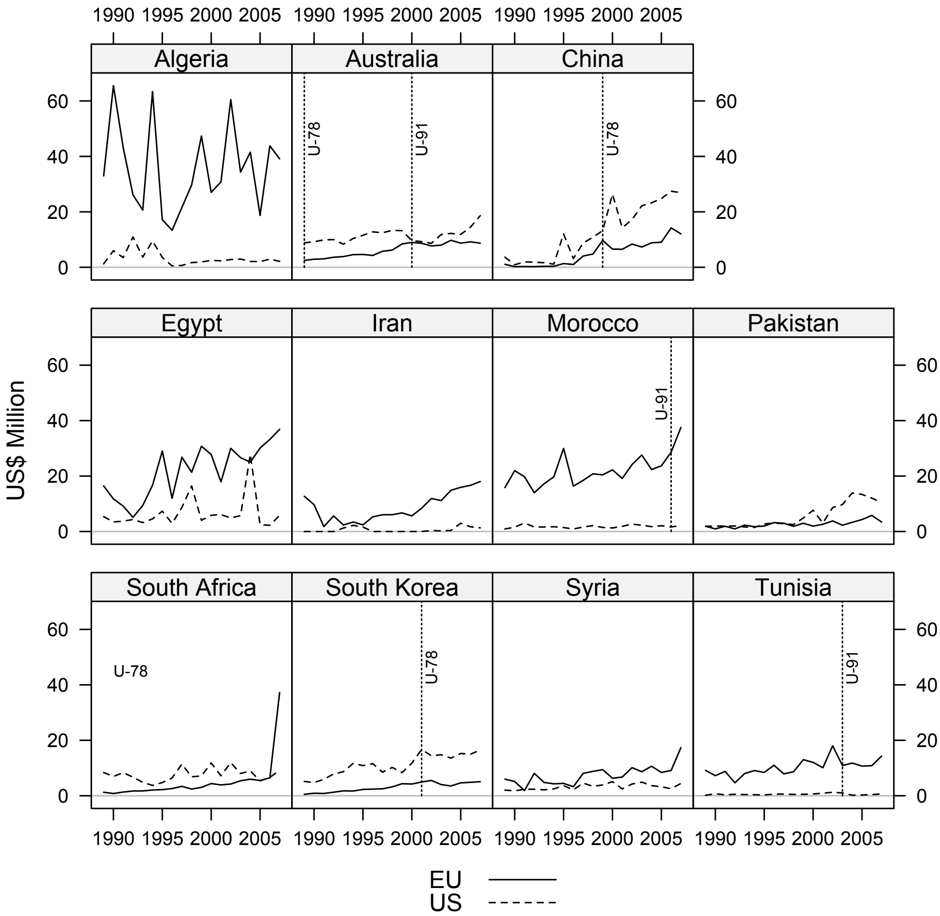


Figure 4: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected Latin American countries (1989-2007) - Group 4 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

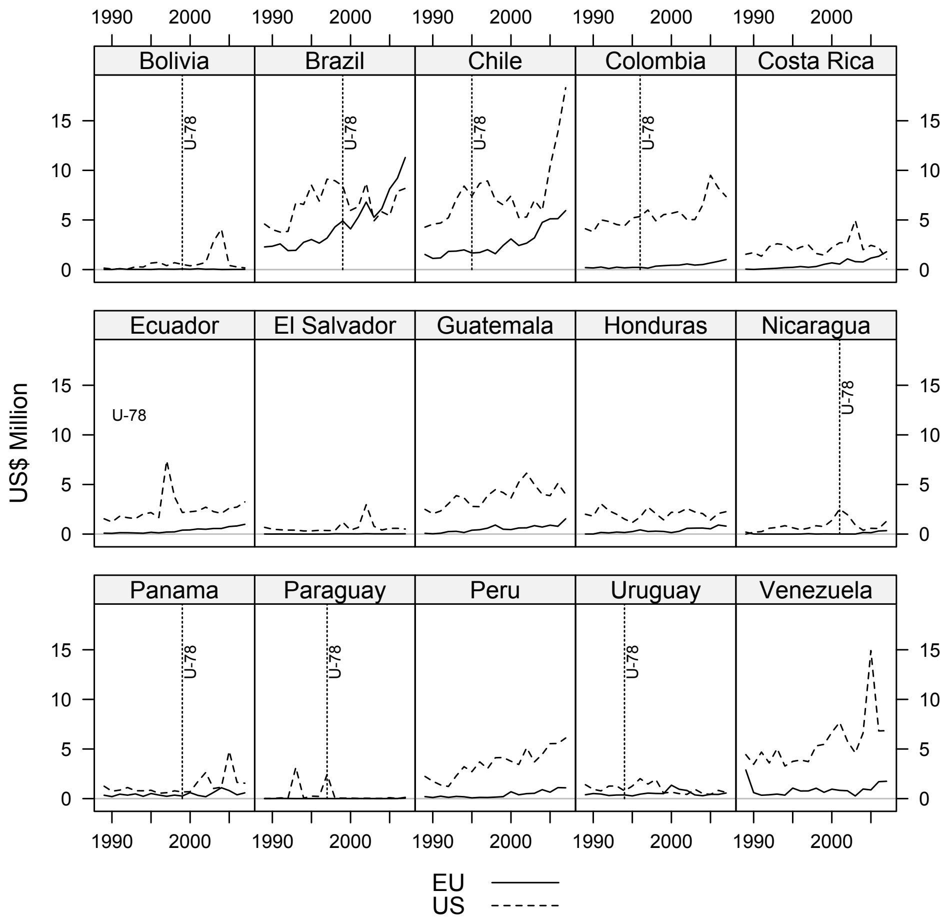


Figure 5: Seed imports (constant US$ 2000) from 10 EU countries and the US for selected countries (1989-2007) - Group 5 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)

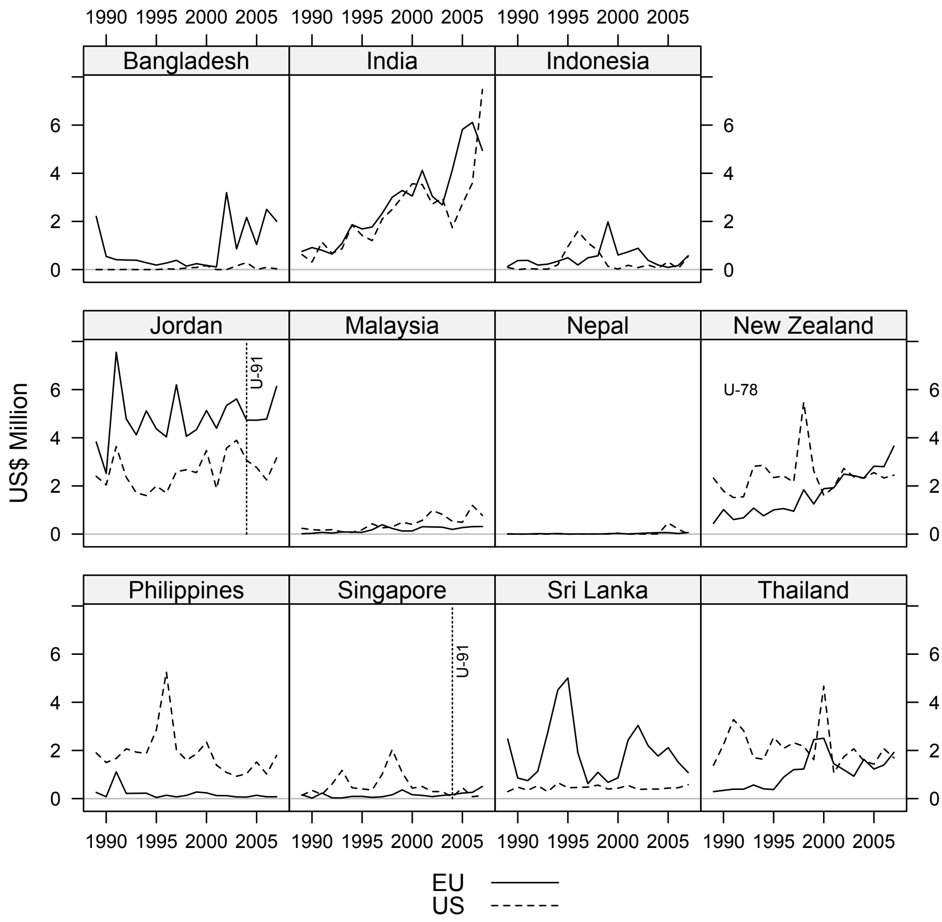
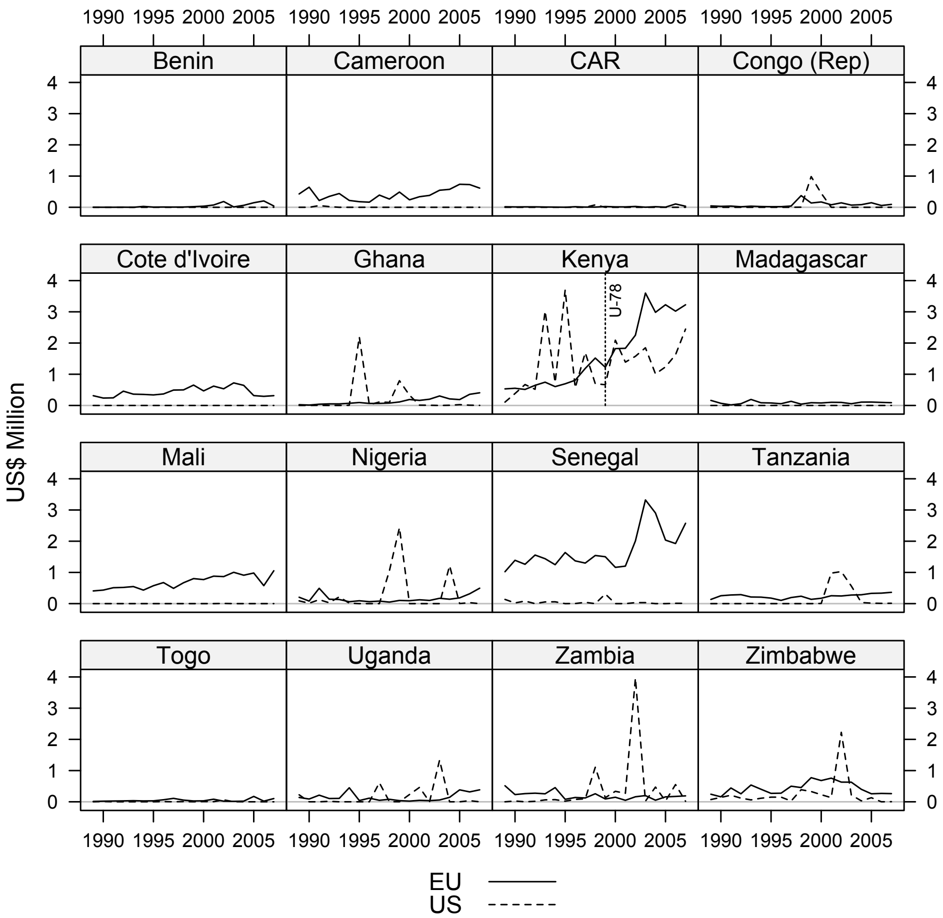


Figure 6: Seed imports (constant US$ 2000) from10 EU countries and the US for selected African countries (1989-2007) - Group 6 (Date of accession to UPOV 1978 or 1991 Acts is also indicated; see text for explanation)



other fairly high-income countries such as Norway and Switzerland have remained with the 1978 Act.[11] 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), 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 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.

[11] 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.

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 and figure 5).[12] 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 6), seed imports really are in value.[13] Kenya and South Africa (the latter shown in figure 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).[14]

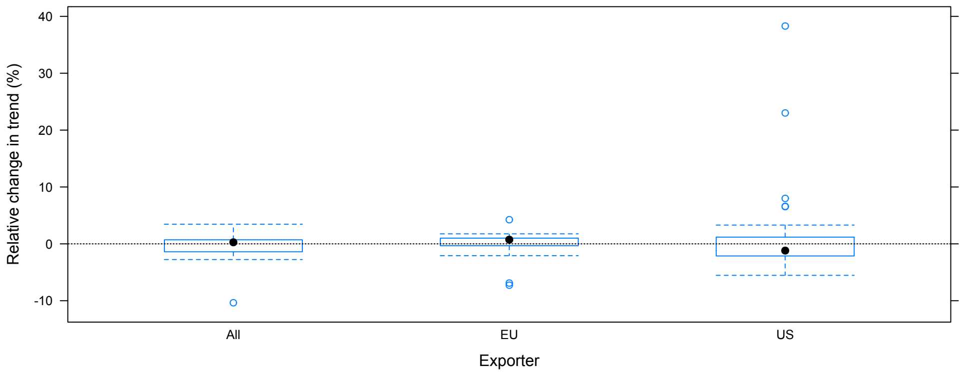
In general then, the figures do not suggest very strong evidence for a positive incentive effect from PBRs on the export of seeds to adopting countries. Taking a simple approach, Figure 7 illustrates boxplots of the proportional increase in trend growth rates in seed imports (by importing country) after the adoption of UPOV compared to before. The trend growth rates before and after UPOV membership are calculated using a three-year moving average of seed imports in order to reduce the influence of initial and final

[12] 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.

[13] 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.

[14] 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.

Figure 7: Boxplots of proportional change in trend growth rates of seed imports pre- and post-UPOV by exporter



Notes: Based on trend growth rates in seed imports calculated using a three-year moving average. The relative change represents the percentage change in the trend rate after UPOV membership relative to before UPOV membership. "All" refers to total seed imports and "EU" and "US", to imports from those sources respectively. Solid dots represent median values.

observations and to smooth out some of the annual variability. If the trend growth rate after UPOV exceeds (is less than) that before UPOV, the value of the relative change in growth rates will be greater (less) than zero. The first boxplot illustrates that the median change in trend rates subsequent to UPOV adoption very slightly positive but not much different from zero, with at the same time a substantial proportion of countries seeing a decline in the trend rate after UPOV membership. Breaking down imports by source, there would appear to be a stronger positive correlation between UPOV membership and imports of seeds from the EU (middle boxplot), while the relationship appears more clearly negative for imports from the US (third boxplot). This suggests that PBRs may play a stronger role for EU exporters than for US exporters and provides further motivation to re-examining the analysis by Yang and Woo (2006) with the additional EU data. The subsequent sections attempt to examine this data more systematically using panel data methods, controlling not only for other factors, but also for unobserved heterogeneity among importing countries.

Tables 7 and 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.

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, non-tariff 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 analyzed the effect of harmonized 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.[15] 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.[16]

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):

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

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} 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,

$$T_{ijk} = D_{ij}^{\delta_k} \prod_g Z_g^{\theta_{ijk}} \tag{2}$$

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):

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

[16] 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.

$$\ln M_{ij} = \ln E_i + \ln Y_j - \ln Y_w + \frac{\delta}{1-\sigma}\ln D_{ij} - (1-\sigma)\ln P_i - (1-\sigma)\ln P_j + \frac{\theta_{ij}}{1-\sigma}\sum_g \ln Z_{gi} \, . \quad (3)$$

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

$$\ln M_{ijt} = \alpha_i + \gamma_j + \mu_t + \beta_E \ln E_{it} + \beta_Y \ln Y_j + \beta_D \ln D_{ij} + \beta_P \ln P_i + \beta_P \ln P_j + \sum_g \beta_g \ln Z_{git} + \epsilon_{ijt} \quad (4)$$

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 $\beta_D = \delta/(1-\sigma)$, $\beta_P = 1-\sigma$, and the vector of coefficients $\beta_g = \theta_{ij}/(1-\sigma)$. 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, (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 fertilizer 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.[17] As in the case of Yang and Woo (2006), it is assumed that a lack of IPRs

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

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.[18] 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 (4).

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

$$\begin{aligned}\ln M_{ijt} \;=\;& \alpha_i + \gamma_j + \varphi_{ij} + \mu_t + \nu_{it} + \pi_{jt} + \beta_E \ln E_{it} \\ & + \beta_D \ln D_{ij} + \beta_{POP} \ln POP_{it} + \beta_{GDP} \ln \left(GDP/cap\right)_{it} \\ & + \beta_{EX} EX_{ijt} + \beta_{U78} UPOV78_{it} + \beta_{U91} UPOV_{it}91 + \epsilon_{ijt} \qquad (5)\end{aligned}$$

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 (3). In 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 (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).[19] In addition, our primary interest is in the effect of time-varying variables, in this case UPOV membership. However, as was seen in 2, for many countries UPOV

[18] 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.

[19] 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.

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 values, which could reflect measurement error.[20] 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 (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.

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

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

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 computational 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.[21]

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

$$y_{it} = \alpha_i + x'_{it}\beta + u_{it} \;\; i = 1, .., N \;\; t = 1, ..., T_i \,, \tag{6}$$

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 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

$$Q_{y_{it}}\left(\tau | x_{it},\, \alpha_i\right) = \alpha_i + x'_{it}\beta\left(\tau\right) \;\; i = 1, ..., N \; t = 1, ..., T_i \,, \tag{7}$$

where $Q\left(\tau|\;\right)$is the conditional quantile function for quantile τ $(0 < \tau < 1)$.[22] 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

$$\underset{\alpha,\beta}{\operatorname{argmin}} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} \rho_\tau \left(y_{it} - \alpha_i - x'_{it}\beta\left(\tau_k\right)\right) + \lambda \sum_{i=1}^{N} |\alpha_i| \tag{8}$$

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 8, making use of sparse linear algebra and interior point methods and available for implementation in `R`.[23] Following the example of Lamarche (2008)[24], we use the panel

[21] 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.

[22] 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 $(0, 1)$.

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

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

bootstrap to estimate confidence bounds for the estimator, sampling with replacement over the importing countries.[25]

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.[26] 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 includes penalized time effects:[27]

$$y_{it} = \alpha_i + \mu_t + x_{it}'\beta + u_{it} \;\; i = 1, .., N \;\; t = 1, ..., T_i \, , \tag{9}$$

with the corresponding quantile regression model,

$$Q_{y_{it}}\left(\tau | x_{it}, \, \alpha_i, \, \mu_t\right) = \alpha_i + \mu_t + x_{it}'\beta\left(\tau\right) \;\; i = 1, ..., N \; t = 1, ..., T_i \, . \tag{10}$$

This can be estimated by

$$\underset{\alpha,\beta}{\operatorname{argmin}} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} \rho_\tau\left(y_{it} - \alpha_i - \mu_t - x_{it}'\beta\left(\tau_k\right)\right) + \lambda_\alpha \sum_{i=1}^{N} |\alpha_i| + \lambda_\mu \sum_{t=1}^{T} |\mu_t| \tag{11}$$

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

[25] We report results for 400 bootstrap replications.

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

[27] 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.

dynamic panel data model with one lag for the dependent variable,

$$y_{it} = \alpha_i + \mu_t + \gamma y_{i,t-1} + x_{it}'\beta + u_{it} \quad i = 1, .., N \quad t = 1, ..., T_i \, , \tag{12}$$

The corresponding dynamic fixed effects quantile regression model is

$$Q_{y_{it}}\left(\tau | x_{it}, \, \alpha_i, \, \mu_t\right) = \alpha_i + \mu_t + y_{i,t-1}\gamma\left(\tau\right) + x_{it}'\beta\left(\tau\right) \quad i = 1, ..., N \; t = 1, ..., T_i \, . \tag{13}$$

Estimation is as with (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.[28] The penalty 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 Data

This section describes the additional data used to estimate (5). Explanatory variables include population, GDP per capita and exchange rates, which are all taken from the

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

World Bank's World Development Indicators database[29], as well as distance between the exporting and importing countries, which is taken from the CEPII GEODIST database commonly used for gravity models.[30]

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.[31] 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 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 fertilizer consumed in a country (metric tonnes and also taken from FAOSTAT).[32] 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 fertilizers are one of the most important. This suggests the use of fertilizer 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.[33] Agricultural GDP is fairly correlated with the value of crop production and generates similar results, as will be seen below.[34]

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

[29]`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.

[30]`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.

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

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

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

[34]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.

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.

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).[35] 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 sub-indices 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 sub-indices are each calculated using objectively verifiable binary questions. However, the process of summing up such questions, both within and across sub-indices means that the index is not based on a uniform measurement scale. Its direct use in regression techniques is therefore not legitimate.[36] 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.[37]

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 ap-

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

[36] 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.

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

plications 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 behavioral change.[38]

Summary descriptive statistics are provided in 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 centered. 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.

Table 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).

[38]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.

5 Results

Our preferred specification is a dynamic model, estimated separately for EU[39] 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 5.1 and 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 lags were included (in either EU or US exports; see below).[40] 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 fertilizer 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 2 and 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 7 and 8 of 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 significantly 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 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 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

[39]Recall from 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.

[40]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.

coefficient at one quantile is found to be significantly 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 7 in the Annex, together with 1 through 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.

A robustness test of these results is undertaken by estimating a similar extended dynamic specification on the larger dataset. As explained above in 4, data on the proxy variables used for an importing country's expenditure on seed imports (value of crop production and fertilizer consumption) were only available for 56 importing countries, a subset of the larger dataset of 79 countries, presented in 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 7), in contrast to the result described above for $\tau = 0.1$ on the smaller sample.[41] 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 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 un-

[41] 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.

derlying 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 significant 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. 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 modeled 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 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 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.

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 the 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 (5), is misspecified. The results of estimating this model are presented in 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 included, 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 fertilizer 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 (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-maximum likelihood estimates are also presented in (4), presenting some marked differences.[42] For example, the coefficients on population and distance from exporter are no longer sig-

[42]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.

nificantly 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 5 and those for the US in 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 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 fertilizer 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.[43] 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 fertilizer consumption 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.

[43] 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.

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 (10)), including the UPOV 1991 variable. For EU exports these are presented in 11 and for US exports in 12, in both cases for five quantiles ($\tau =$ 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.[44] It is important to recall that these estimates are for a two-way specification, including both importer country effects and time effects.[45]

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 $\tau =$ 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 $\tau =$ 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 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

[44]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 3, variation both between and within importing countries is incorporated in the estimates, even where the explanatory variable does not exhibit variance over the period of the sample for some of the countries.

[45]A one-way specification of the models in 11 and 12 was also estimated which produced fairly similar results (not shown).

HT and Poisson models. Possible explanations for this result exist[46] but the lack of explanatory power in a number of the principal gravity equation variables suggests first examining omitted, time-variant heterogeneity 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.

[46]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 1 to 6 suggests some specific countries which might account for such an effect, such as France, Italy, Bulgaria and Hungary in Europe.

Table 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 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 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.

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 (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 9 and Table 10 on page 47 respectively and the results are quite different from those of the static models.[47] 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 significant 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

[47] 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 the countries is also strongly rejected for both sets 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).[48] 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.[49] 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.[50] 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.[51] 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[52]). Perhaps the quantile regression framework is more robust than OLS to this potential misspecification, but this issue does not appear to

[48] 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.

[49] 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).

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

[51] 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.

[52] 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.

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

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[53] 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 modeling, which includes other conditional mean approaches such as random coefficients, random parameters, and semi-parametric models.

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

[53] 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.

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 paper, 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.

7 Annex

7.1 Countries sorted by quintiles of seed imports

Table 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

0.2	0.4	0.6	0.8	1.0
				Netherlands
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 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

0.2	0.4	0.6	0.8	1.0
	China	China	China	China
		Colombia	Colombia	
	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

0.2	0.4	0.6	0.8	1.0
	Uruguay	Uruguay		
		Venezuela	Venezuela	Venezuela
Zambia	Zambia	Zambia		

7.2 Additional results

7.2.1 Quantile regression estimates of simple dynamic model

Table 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 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.

7.2.2 Quantile regression estimates of static model

Table 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 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.

7.2.3 Quantile regression estimates for larger dataset

Table 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 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.

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Table 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.

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