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The role of intellectual property rights in seed technology transfer through trade: evidence from U.S. field crop seed exports

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Abstract

A panel of 134 countries over the period 1985–2010 is used to evaluate the effect of intellectual property rights (IPRs) on field crop seed imports from the United States. Based on estimating a gravity equation using the Heckman selection and Poisson fixed-effects panel econometric methods, the results indicate that membership of countries in both the International Union for the Protection of New Varieties of Plants and the Trade-Related Aspects of Intellectual Property Rights Agreement of the World Trade Organization have a positive and statistically significant effect on their imports of U.S. field crop seeds. These results, however, are also sensitive to both income level of importing countries and better enforcement of IPRs by those countries.

JEL classifications: F14, O34, Q17

Keywords: Intellectual property rights; Seed trade; Gravity equation

1. Introduction

With a growing world population but limited land and water resources, technology is key to raising agricultural productivity (Campi, 2017). Investment in improved seed varieties has been shown to increase agricultural output per unit area of land (Lence et al., 2016), although the use of such seeds, especially by smallholder farmers in developing countries, is highly dependent on local market characteristics, for example, Shiferaw et al. (2008, 2015), Smale and Olwande (2014), and Wainaina et al. (2016). Access to new technology is also very dependent on the extent of intellectual property (IP) protection afforded to seed firms that innovate.

There is no consensus in the literature about the effect of intellectual property rights (IPRs) on innovation and agricultural productivity. For example, Kolady and Nesser (2009) report that IP protection in the United States has contributed to the genetic improvement of wheat varieties. In contrast, Campi (2017) finds that while strengthening of IPRs over the period 1961–2011 had a positive effect on wheat and maize productivity in a sample of high- and low-income countries, it did not for middle-income countries. There is also debate about whether IP protection will improve access to plant breeding innovations: on the one hand, the International Union for the Protection of New Varieties of Plants (UPOV, 2005) claims that stronger IPRs will broaden the domestic and international scope of new seed varieties; on the other hand, concern is often expressed that the monopoly power conferred through IPRs will deter local innovation and technology transfer in the seed sector (Campi, 2017).

International trade is one channel through which seed firms transfer proprietary technology, subject to the effectiveness of IP protection in the destination market (Grossman and Helpman, 1995). In this context, the objective of the research presented in this article is to assess the effect of a country's IPRs on its field crop seed imports from the United States. The focus is on field crop seeds because growth in the U.S. seed market has been particularly rapid for major field crops (Fernandez-Cornejo, 2004), and the major genetically modified (GM) varieties are all field crops (James, 2015). The key contributions of the article are: first, to account for zero trade observations, both selection and Poisson fixed-effects econometric methods are used to fit a gravity model with a panel data set of 134 countries over the period 1985–2010, where the latter is regarded as the preferred econometric model; second, to account for the sample containing countries at different levels of development,

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the IPR variable representing UPOV is interacted with variables reflecting both their income status and the quality of their legal enforcement; and third, estimation of the Poisson fixed-effects model, the more robust econometric method, provides statistically significant support for the hypotheses that implementation of IPRs has a positive impact on U.S. seed exports. It should be noted, however, that this result is very sensitive to the income level and the legal environment strength of importing countries—specifically, U.S. seed exports to members of UPOV are positive for importing countries with high GDP per capita and strong enforcement of IPRs.

The remainder of the article is organized as follows. In Section 2, institutional details of IP protection for seeds are outlined, followed in Section 3 by a review of a selected number of previous studies on IPRs and trade; in Section 4, the model framework and estimation methodology are outlined, while in Sections 5 and 6, the data and estimation results are reported; finally Section 7 contains a brief summary of the article along with some conclusions.

2. IP protection of seeds

Improved seed varieties, together with fertilizers, pesticides, herbicides, and irrigation, have been responsible for much of the observed increases in global agricultural yields (UPOV, 2009). However, development time and high costs associated with plant breeding puts small seed companies at a disadvantage in research and development (R&D). Plant breeding companies typically reinvest 12–15% of their sales in R&D with the top 20 companies spending $4 billion every year on R&D (International Seed Federation [ISF], 2015). Moreover, the development cycle for a new variety usually takes 10–15 years. As a result, seed IPRs are concentrated in the hands of a few large U.S. and European firms such as DuPont, Monsanto, and Syngenta (Clancy and Moschini, 2017), the top four firms accounting for 54% of the global seed market in 2009 (Heisey and Fuglie, 2011).

The self-replicating nature of (nonhybrid) seeds makes plant breeding innovations particularly susceptible either to imitation with minimal difficulty or at a low cost. Nonexistent or insufficient IP protection jeopardizes breeders' interests and reduces private incentives for further innovation. With the advent of GM crops, the relevance and significance of IPRs have been intensified as more proprietary seed technologies are involved (Wright, 2007). IPRs such as plant breeders' rights (PBRs) have been established to regulate the seed market and confer exclusive rights for a limited time period, providing an incentive for plant breeders to finance R&D (Lence et al., 2016).

The application of IPRs to plant varieties is a relatively recent phenomenon (Srinivasan, 2005). In the United States, PBRs were defined by the 1970 Plant Variety Protection Act, under which the U.S. Department of Agriculture (USDA) issues Plant Variety Protection Certificates (PVPCs), the latter issued to varieties that are new, and satisfy the requirements of distinctiveness, uniformity, and stability (Lesser, 2007). PVPCs provide IP protection for 20 years, similar to a U.S. patent, with two qualifications: seeds of protected varieties can be saved and subsequently replanted by farmers (*farmers' privilege*), although they are prohibited from reselling saved seeds; and, there is an exemption whereby protected varieties may be used by other breeders for the purposes of experimentation and research aimed at developing other new varieties (*breeders' exemption*).

International coordination of PBRs occurs through UPOV. UPOV was originally agreed in 1961 by a group of European countries, and established PBRs similar to those contained subsequently in U.S. legislation. The rights defined by UPOV focus on the maintenance of commercial exclusivity for a defined period, although the eligibility standard for protection is lower than that for patents (Clancy and Moschini, 2017). The most recent UPOV Act of 1991 extended its species coverage and length of protection (20 years), although farmers' privilege is now an option for member states. Importantly, the 1991 Act introduced the concept of *essentially derived variety* (EDV) designed to deal with interaction between PBRs and patents. Under the research exemption, a plant breeder is able to insert a patented GM trait into an initial variety protected by PBRs, thereby generating an EDV, but approval by the owner of the initial variety, as well as profit sharing, would be required before marketing of the EDV could proceed (Moschini and Yerokhin, 2007).

To harmonize IPR regimes, the World Trade Organization (WTO) Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) went into effect on January 1, 1995. It makes protection of IPRs an integral part of the multilateral trading system. TRIPs has made a set of minimum IP standards a requirement for all of its members, and is to date the most comprehensive multilateral agreement on IP. Furthermore, Article 27.3(b) of TRIPs also extends IPRs to new plant varieties by stipulating that countries must provide for protection of seeds and plant varieties either by patents, or an effective *sui generis* system, such as the PBRs provided in the conventions of UPOV, or by any combination of the two. Consequently, a country might provide UPOV-like protection as a result of it signing the TRIPs agreement—44 countries have in fact become members of UPOV since 1995. As well as harmonization of IPR regimes, perhaps the most important function of TRIPs is provision of international enforcement through the WTO dispute-settlement mechanism (Clancy and Moschini, 2017). Campi and Nuvolari (2015) also present empirical evidence indicating that membership of TRIPs resulted in significant strengthening of IP protection for plant varieties by both high- and low-income countries.

Although subject to IPRs, trade in GM crops may also be affected by their acceptance/approval status in different countries (Gruère, 2011). GM crops have been grown commercially since 1996, initially in 6 countries on 1.7 million hectares, increasing to 29 countries with 180 million hectares under cultivation by 2015 (James, 2015). Despite rapid adoption, Barrows et al. (2014) report that the global area of GM crops harvested is highly concentrated in terms of crops: corn, cotton, canola, and soybeans; and countries: United States, Brazil, Argentina, India, and Canada. Outside these countries, the share of land area devoted to GM crops was 2% or less for the majority of countries growing GM crops in 2015 (James, 2015).

3. IPRs and trade

IPRs are a contentious issue, particularly between developed (the North) and developing countries (the South; Grossman and Lai, 2004). In a closed economy, tougher IPRs generate an economic trade-off: incentives for innovation versus reduced competition between innovating firms. Therefore, optimal patent policy equates marginal dynamic benefits with marginal static efficiency losses (Nordhaus, 1969). However, in an open economy, some benefits of innovation by domestic firms may accrue to foreign firms. A body of theory has focused on the effects of strengthening IPR regimes.

A series of studies published in the 1990s treat R&D as a one-off event. For example, Chin and Grossman (1990) use a partial equilibrium setting with duopoly, where a firm in the North innovates recognizing that the IPR regime determines the extent of imitation by a firm(s) in the South. Their results show failure of the South to protect IP reduces innovation, and hence welfare in the North, but the South gains from imitation, unless its share of world consumption of the product is very large. Deardorff (1992) focuses on multiple product innovation in the North, where IPR enforcement in the South results in losses from monopoly pricing, thereby outweighing any benefits of new product introduction. Alternatively, Diwan and Rodrik (1991) by assuming North and South have different preferences for innovation, show that the South benefits from tougher protection of IP because it allows firms in the North to develop products benefitting consumers in the South. Taylor (1993) assumes a duopoly setting where a firm in the North innovates, and depending on the stringency of IPRs, may undertake expenditures to deter imitation of their innovation by the firm in the South, while the firm in the South may invest resources in reverse-engineering the innovation. In this setting, the South has an incentive to implement weak IPRs in order to shift rents to its firm, but it can be Pareto-improving to move to an intermediate IPR regime where fewer resources are employed in imitation and reverse engineering.

With ongoing R&D, Grossman and Helpman (1990) assume economic growth depends on learning-by-doing in a single sector. R&D by firms in the North generates market power allowing firm(s) to earn oligopolistic rents over time, but due to knowledge spillovers, these rents are dissipated through imitation by firms in the South. Trade speeds growth in both North and South, despite imitation by firms in the South, due to the expected present value of returns on innovation in the North actually increasing with trade. However, this result is sensitive to the extent to which protection of IP affects the rate of technological diffusion.

Helpman (1993) focuses on tightening IPRs in the South, assuming that the South has an initial cost advantage, and its firms compete via imitation. He shows that if the rate of innovation is exogenous, and imitation is high in the South, a tougher IPR regime always hurts the South, while the North may win or lose depending on whether terms of trade gains outweigh losses from inefficient interregional resource allocation. If the rate of innovation is endogenous, tougher IPRs initially prompt an increased rate of innovation followed by a decline as the share of products that have not been imitated increases. The North benefits from this shift in the time pattern of available products, but the initial increase in the rate of innovation is not enough to outweigh the terms of trade loss to the South and the negative welfare effect of the reallocation of production from South to North. Helpman (1993) concludes that the South never benefits from tougher IPRs.

Clearly, the relationship between innovation and the IPR regime is subtle, and there will be tension between the North benefiting from and the South losing from a tougher IPR regime. The North typically benefits from its firms grabbing a greater share of the export market, while the South is hurt by its firms losing market share in combination with consumers facing higher prices as firms in the North extract monopoly rents, that is, there are two counteracting effects of IPRs: *market expansion* and *market power* (Maskus and Penubarti, 1995). The former effect increases exports to countries with stronger IPRs as a result of increased demand due to less imitation by local firms, reinforced by a *cost reduction* effect as exporting firms expend fewer resources on hiding innovations. In contrast, trade flows may decrease through the latter effect, due to holders of IPRs raising prices and restricting exports. The net effect of IPRs on trade depends on the relative magnitude of these effects, that is, it is essentially an empirical question.

Previous studies of trade in manufactures have found IPRs to have a positive effect on exports, for example, Maskus and Penubarti (1995), Smith (1999), and Ivus (2010), while Campi and Dueñas (2016) found that stronger IPRs have had a negative effect on trade in agricultural products. In the case of seed trade, Yang and Woo (2006) and Eaton (2009) both failed to detect a statistically significant effect of IPRs, while Galushko (2012) found the positive impact of IPRs varied across different groups of crops. The current article builds on these previous studies by utilizing a larger data set and focusing on field crop seeds that include seeds susceptible to IPR infringement.

It should also be noted that while the theoretical literature on trade and IPRs has focused almost exclusively on North–South trade, given that the U.S. exports seeds to countries in the North as well as the South, explicit account is taken in the current analysis of both interaction between IPRs and level of development, as well as using country fixed effects and other variables in the gravity equation to account for differences across importers.

4. Model framework and estimation

4.1. Gravity model

The gravity model predicts that the volume of trade between two countries will be proportional to their GDPs, and inversely related to the distance between them:

$$X_{ij}^k = \alpha(Y_i)^{\beta_1}(Y_j)^{\beta_2}(D_{ij})^{\beta_3}, \tag{1}$$

where X_{ij} is the value of exports (imports) by country i to j (i from j) in sector k, $Y_i(Y_j)$ is the value of nominal GDP in i(j), D_{ij} is the distance from i to j. In stochastic form, (1) is written as

$$X_{ij}^k = \alpha(Y_i)^{\beta_1}(Y_j)^{\beta_2}(D_{ij})^{\beta_3}(\boldsymbol{A}_{ij}^k)^{\beta_4}u_{ij}^k, \tag{2}$$

where $\boldsymbol{A}_{kj}^i$ is a vector of other factors, such as free trade agreements (FTAs) and tariffs, that may positively/negatively impact trade between i and j in sector k, and u_{ij}^k is a log-normally distributed error term with $E(\ln u_{ij}^k) = 0$.

Until recently, the conventional view in international economics was that the gravity equation lacked microeconomic foundations (Head and Mayer, 2014). However, it is now considered general enough to be applied beyond a subset of countries or sectors (Anderson and van Wincoop, 2003; Arkolakis et al., 2012; Eaton and Kortum, 2002), and that importer and exporter fixed effects can be used to account for the multilateral trade resistance terms derived from different theoretical models (Feenstra, 2004).

In addition, evaluating (2) on the basis of exports (imports) to (by) country j, at the firm/industry/sector-level as opposed to the economy-wide level using bilateral trade, has a clear analytical justification, drawing on a range of trade theories, for example, Melitz (2003), Anderson and van Wincoop (2004), Chaney (2008), Anderson and Yotov (2010a, 2010b, 2012), Costinot et al. (2012), and Costinot and Rodríguez-Clare (2014).[1] As a result, robust estimation of firm/industry/sector-level gravity equations using export (import) data is now common in the agricultural economics literature, some recent applications including Jayasinghe et al. (2010 ;U.S. corn seed exports), Cardamone (2011) (fruit exports), Chevassus-Lozza and Latouche (2012) (French firms' agrifood exports), Philippidis et al. (2013; 95 countries' agrifood exports), and Dal Bianco et al. (2016) (wine exports).

[1] Anderson and Yotov (2010a; 2010b) argue that early attempts to estimate gravity models using disaggregated data were likely unsuccessful due to the failure to use fixed effects to control for multilateral trade resistance at the industry/sector level. They also note that estimating aggregate gravity models reveals extensive bias, which can be reduced through the estimation of industry/sector-level gravity equations.

4.2. Estimation

The conventional approach is to linearize the model by taking logs of (2), and applying ordinary least squares. However, this approach potentially suffers from an omitted variables problem. Where controls such as common membership of an FTA are used to account for the propensity of a country j to import seeds from the United States, the estimates may be biased if there is some unobserved component to this propensity to import. One way of dealing with this unobserved heterogeneity is to use a fixed-effects model, with dummy variables introduced to account for the effects of those omitted variables specific to each importing country j, but which stay constant over time t (Hsiao, 1986). A dummy variable specific to each time period t, but the same across all importing countries j is also introduced. Given the panel data set used in the current analysis, this would take the following form, where lowercase variables are the logs of their respective uppercase variables, and dropping the sector-superscript k:

$$x_{jt} = \alpha_j + \gamma_t + \boldsymbol{\beta}'\boldsymbol{y}_{jt} + \mu_{jt}, \tag{3}$$

where x_{jt} denotes field crop seed imports by country j from the United States during year t, $\boldsymbol{y}_{jt}$ is a vector containing κ regressors, $\boldsymbol{\beta}'$ is a $1x\kappa$ vector of constants, α_j and γ_t are importing country and time fixed-effects, respectively, and μ_{jt} is a mean zero error term.

However, estimation of (3) may be inconsistent for two key reasons: first, if there are zero trade observations in the data, how these are handled may either result in selection bias (Westerlund and Wilhelmsson, 2011) or inconsistent estimates of the coefficients of interest (Santos Silva and Tenreyro, 2006); and second log-linearization of (2), even with country fixed effects, results in biased and inefficient estimates in the presence of heteroscedasticity (Santos Silva and Tenreyro, 2006).

Santos Silva and Tenreyro (2006) note the analogy between the concept of Newtonian gravity and trade is not exact, that is, while gravitational force can be small but never zero, trade between countries can be zero for various reasons, for example, exporter and importer fixed costs (Anderson and van Wincoop, 2003), and firm-level productivity (Helpman et al., 2008). The key is that log-linearization of the gravity equation is not defined for observations with zero trade between countries.

In the data set used in the current article, zeros constitute approximately 49% of the recorded import observations. If the zeros are treated as true zeros, as opposed to missing values, in order to avoid selection bias, they have to be dealt with using other econometric techniques. Two methods have become common in the literature: a sample selection framework due to Helpman et al. (2008), which nests Heckman's (1979) selection model, and a Poisson regression model, suggested by Santos Silva and Tanreyro (2006), that predicts both zero and positive trade values.

Helpman et al. (2008) develop a two-stage estimation procedure that generalizes the gravity equation by taking into account the extensive and intensive margins of trade, that is, the choice of whether to export to country j, and if so how much to export. Following Melitz (2003), a gravity equation is derived with a new variable controlling for the fraction of firms exporting to j. As the latter variable is typically not observable, a latent variable, Z_{ij} is defined as the ratio of variable export profits for the most productive firm(s) in country i to the fixed costs of exporting to country j. Although Z_{ij} is not observable, positive exports occur only when $Z_{ij} > 1$. Therefore, in the first stage, the probability of exports from country i to j, conditional on observed variables, can be estimated using a Probit equation, and the inverse Mill's ratio computed. In the second stage, a log-linearized gravity equation is estimated only for the observed trade flows, where sample selection bias is corrected through inclusion of the inverse Mills ratio from the first stage.

In her study of seed exports, Galushko (2012) used the Heckman (1979) selection model to deal with the problem of zero trade observations, the latter method being valid when there is no firm-level heterogeneity (Helpman et al., 2008). A similar technique was adopted by Jayasinghe et al. (2010) in their analysis of the impact of trade costs on U.S. corn seed exports. This seems reasonable for the current sample where U.S. firms are productive enough to export seeds (50% of trade observations in the sample are not zero), but the range of countries they select to export to (the extensive margin) and the amount they choose to export (the intensive margin) is a function of a vector of destination-specific effects. Therefore, in the current study the Heckman model is applied first to a crop seed data set, with the first- and second-stage equations:

$$Prob(T_{jt} = 1) = \Phi(\alpha_j + \gamma_t + \boldsymbol{\beta}' \boldsymbol{y}_{jt} + \mu_{1jt}) \tag{4}$$

$$x_{jt} = \alpha_j + \gamma_t + \boldsymbol{\beta}' \boldsymbol{y}_{jt} + \rho\sigma\eta_{jt} + \mu_{2jt}, \tag{5}$$

where $T_{jt} = \{\begin{matrix} 1 \text{ if} x_{jt} > 0 \\ 0 \text{ if} x_{jt} = 0 \end{matrix}\}$, Φ is the cumulative density function of a standard normal distribution, $\mu_{1jt} \sim N(0, 1)$, $\mu_{2jt} \sim N(0, \sigma)$, $corr(\mu_{1jt}, \mu_{2jt}) = \rho$, and η_{jt}= the inverse Mill's ratio.

A recent article by Santos Silva and Tenreyro (2015) raises two doubts about the statistical validity of this estimation methodology. First, they argue that the proposed estimator is very sensitive to heteroscedasticity compared to estimation of traditional gravity models that can be made heteroscedastic proof. Second, they suggest that implementation of the proposed estimator, which requires a suitable exclusion restriction for identification of the second-stage equation may result in biased estimates, even if a valid instrument can be found and the errors are homoscedastic.

As an alternative Santos Silva and Tenreyro (2006) have proposed using a Poisson maximum likelihood (PML) method for estimating the gravity equation. Estimation via PML is shown to be robust to different patterns of heteroscedasticity, and is also a logical way of including zero observations of the dependent variable in the estimation. Therefore, the following equation is estimated using a PML methodology, with uppercase variables representing levels:

$$X_{jt} = exp(\boldsymbol{\beta}' \boldsymbol{Y}_{jt} + \alpha_j + \gamma_t) + e_{jt}, \tag{6}$$

where e_{jt} is a mean zero error term.

One concern raised about the PML method is that it may generate biased estimates if there are a large number of zero observations in the data (Burger et al., 2009; Martin and Pham, 2008; Martínez-Zarzoso et al., 2007). Santos Silva and Tenreyro (2011a) have subsequently shown through Monte Carlo simulations that PML performs well even with a large proportion of zeros in the sample.

5. Data

The data set comprises a panel of 134 countries spanning 1985–2010, of whom 95 and 39 are defined as low- and high-income, respectively (World Bank; see Supporting Information Appendix Table A1). Countries included in the sample consist of those that were importing field crop seeds from the United States at least once during the period and for which there are no missing values of any explanatory variables. We have chosen 1985 as the starting point, the year when global seed trade began growing rapidly, followed by growth in U.S. field crop seed exports (ISF, 2011). A description of the data sources is given in Table 1, while summary statistics for all variables are provided in Table 2 (see Supporting Information Appendix Table A2 for the correlation matrix). The dependent variable is the value of annual national field crop seed imports from the United States (*seedIMP*). The explanatory variables are grouped into two categories: (1) country economic and market sizes, and (2) potential trade enhancers/barriers. As noted earlier, the traditional gravity equation also includes geographic distance between trading nations, but since only fixed-effects models are used in the current analysis, this time-invariant factor is excluded.

Following Yang and Woo (2006), category (1) variables include country GDP per capita (*logGDPCap*), population (*logPop*), and lagged crop production (*llogCropProd*). The inclusion of GDP per capita and population as opposed to GDP alone is quite common in the empirical literature on gravity equations, for example, Frankel and Rose (2002), Frankel et al. (1995), and Rose (2004). Frankel (1997) has shown that gravity equations including combinations of either GDP and GDP per capita, GDP and population, or GDP per capita and population are mathematically equivalent. In the current setting, higher GDP per capita and population are both expected to have a positive effect on seed imports from the United States (Frankel, 1997; Larue and Mutunga, 1993). Gravity equations of this form also usually include the exporting country's GDP per capita and population. However, since the United States is the only exporting country in the sample, its coefficient is absorbed into

Table 1
Data sources

Variable	Definition	Data source
seedIMP	Field crop seed imports from United States (U.S.$)[a]	USDA's GATS (Global Agricultural Trade System)
GDPCap	GDP per capita (constant 2000 U.S.$)	World Bank's *World Development Indicators*
Pop	Population	World Bank's *World Development Indicators*
CropProd	Combined production of cereals, coarse grain and oil crops (tons)	FAOSTAT
growGM	GM crop-planting status	James, C. *Global Status of Commercialized Biotech/GM Crops*, 1996–2010
UPOV	UPOV member	UPOV web site
WTOTRIPs	WTO members that have implemented TRIPs	WTO web site
law	Index capturing quality of contract enforcement and property rights	*Worldwide Governance Indicators* web site
legal	Index capturing quality of legal system	Fraser Institute
FTA	Free trade agreement	Office of the United States Trade Representative web site
free	Index capturing freedom to trade	Fraser Institute

[a]Adjusted to 2000 price using U.S. Bureau of Labor Statistics' export price index for agricultural commodities.

Table 2
Summary statistics

Variable	Obs.	Mean	SD	Min	Max
seedIMP	3,214	1,760,211	7,441,764	0	1.25E + 08
GDPCap	3,211	5,834.36	8,735.98	101.34	56,285.28
Pop	3,211	4.16E + 07	1.44E + 08	62,192	1.34E + 09
CropProd	3,214	1.81E + 07	5.80E + 07	98	7.00E + 08
growGM	3,214	0.0746733	0.2629044	0	1
UPOV	3,214	0.420037	0.493641	0	1
WTOTRIPs	3,214	0.3571873	0.4792452	0	1
law	3,214	−0.06244	1.010347	−2.5	2.06622
legal	2.911	5.415588	1.824042	0.1112424	9.901896
FTA	3.214	0.0364032	0.1873205	0	1
free[a]	2.951	6.513998	2.114742	−2.22	18.1

[a]Data unavailable across 11 countries in sample.

the time fixed effects. Lagged crop production refers to a country's combined production of cereals, coarse grain, and oilseed crops in the previous period, which is expected to affect demand for field crop seeds in the current period. This variable is also lagged in order to avoid any potential issue of endogeneity.

For category (2) variables, a dummy variable is included for FTAs (*FTA*), where both importing country and the United States are members. FTAs generally open up foreign markets to U.S. exporters by reducing barriers such as tariffs. Also included are dummies for UPOV (*UPOV*) and TRIPs (*WTOTRIPs*) membership. Initially used by Ferrantino (1993), and the three previous studies of seed trade, membership of IPR-related organizations is treated as a proxy for national differences in IPRs. The first UPOV Convention went into force in 1968. Its two most recent revisions are referred to as the "1978 Act" and "1991 Act," of which almost all of its 74 member states are signatories (not including the EU), where Belgium is the only country that is still on the 1968/1972 Act. The 1991 Act is more strict in terms of coverage, period, scope, and exemptions. The United States has been a UPOV member since 1981 and upgraded to the 1991 Act in 1999. It is reasonable to assume that U.S. seed companies will have more IPR concerns when they decide to export to a country that is not a UPOV member or only conforms to the 1978 Act. Even though new members can no longer sign up to the 1978 Act, the existing members sticking with the 1978 Act are not obligated to upgrade. As of 2010, among the countries considered for this study, 63 are UPOV members, 17 adhere to the 1978 Act, and 46 are signatories of the 1991 Act, of which 14 upgraded from the 1978 to the 1991 Act (see Supporting Information Appendix Table A3). It should also be noted that UPOV membership increased from 30 to 48 countries in 1991, and then to 60 countries in 1995, with no significant increase for the remainder of the sample period.

To capture the effect of TRIPs, an indicator variable is employed: *WTOTRIPs* refers to WTO members in the sample that have implemented TRIPs, of which a total of 96 countries in the current sample had done so by 2010. Two discrete jumps are also observed in the data: 26 and 91 countries had implemented TRIPs by 1996 and 2000, respectively. These jumps reflect different transition periods of time to delay applying TRIPs' provisions, based on the levels of economic development of WTO members. Specifically, developed countries were granted one year to ensure their laws and practices conform to TRIPs, such that by 2010, 38 developed countries in the sample were applying TRIPs, of whom 23 had signed the Agreement by 1999. Developing countries and (under certain conditions) transition economies were given a further four years to apply TRIPs' provisions by January 1, 2000, 58 developing countries in the sample applying TRIPs by 2010. Of the remaining 38 countries in the sample, 19 are least developed countries that had been granted a TRIPs transition period until July 1, 2013.

Using binary variables to capture the effect of membership of IPR agreements does have drawbacks. Here the assumption is that as a member of such an agreement, regardless of how long membership has been, the effect is the same across countries. One would think that a long-standing member will be more effective in providing IPR protection than a new member. However, as discussed in Yang and Woo (2006), binary IPR variables are not ideal for capturing the implementation and enforcement of IPR laws. Even though the TRIPs council reviews the legislation of members after their transition periods have expired, the actual implementation and enforcement of IP laws is still largely unknown.

An alternative is to use membership of IPR agreements in combination with some index of the degree of IP protection offered in a country. For example, patent rights indices have been constructed by Ginarte and Park (1997), and Park (2008). Among the previous studies of seed trade, Yang and Woo (2006) chose not to include any such index in their empirical analysis, including instead a set of dummy variables capturing the level of economic development of seed importing countries in their sample, which assumes that higher development levels are correlated with stricter enforcement of IP. In contrast, Eaton (2009) used an index for the strength of IP protection compiled by the *Economic Freedom of the World* database produced by the Fraser Institute (Gwartney et al., 2016), although he found no statistically significant impact for this index on seed trade. Galushko (2012) also included a dummy variable for high-income importing countries in her sample, but in a footnote she indicates the "Rule of Law" indicator included in the World Bank's *Worldwide Governance Indicators* (WGI; Kauffman et al., 2010) was also used. Galushko (2012) found that the latter variable was highly correlated with the dummy variable for high-income countries, her estimation results proving robust to using either measure of property rights enforcement.

In the current study, the level of economic development is likely captured by country fixed effects. Therefore, the choice was made to include a variable *law*, based on the "Rule of Law" indicator, in order to capture the potential for IPR enforcement among the panel of importing countries. This indicator is defined as, " . . . capturing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, courts, as well as the likelihood of crime and violence . . . " (Kaufmann et al., 2010, p. 4).

In the WGI analysis, the aggregate score for rule of law was updated biannually between 1996 and 2002, and annually thereafter. Given the time period of the current study is 1985–2010, the variable *law* is based on the available data from WGI, where the missing years 1997, 1999, and 2001 are interpolated as the average of the preceding and succeeding years, and the missing years 1985–1995 extrapolated based on fitting a linear regression to the observed WGI data.

Finally, a dummy variable is included in the estimation, representing the planting status of GM crops (*growGM*). Unlike membership of UPOV or TRIPs, GM crop-planting status is not necessarily invariant once started. In the EU, planting of GM crops was discontinued during the early 2000s as several countries banned GM crops around the time that the EU moratorium on GM crop approval was in effect. If a country grows GM crops, it is reasonable to expect that it will have a higher demand for bioengineered seeds, of which the United States is both a major producer and exporter. However, due to the concentration of ownership of biotechnology patents among a few multinational firms, it is also possible that seed imports of a country growing GM crops will be reduced either because of the market power effect identified earlier, the foreign direct investment choices of multinational firms (Galushko, 2012), or local development of GM crops in markets such as Brazil and Argentina (Franke et al., 2009; Massarani et al., 2013).

6. Results

6.1. Heckman model

The following first- and second-stage equations are estimated:

$$\begin{aligned} Prob(T_{jt}=1) = \Phi[&\delta_1 logGDPCap_{jt} + \delta_2\, logPop \\ &+ \delta_3 logCropProd_{jt-1} + \delta_4 growGM_{jt} \\ &+ \delta_5 UPOV_{jt} + \delta_6 UPOVhigh_{jt} \\ &+ \delta_7 WTOTRIPs_{jt} + \delta_8 law_{jt} + \delta_9 FTA_{jt} \\ &+ \delta_{10} free_{jt} + \alpha_j + \gamma_t + \mu_{jt}] \end{aligned} \tag{7}$$

$$\begin{aligned} logseedIMP_{jt} = \beta_0 &+ \beta_1 logGDP_{jt}Cap + \beta_2 \log Pop \\ &+ \beta_3 logCropProd_{jt-1} + \beta_4 growGM_{jt} \\ &+ \beta_5 UPOV_{jt} + \beta_6 UPOVhigh_{jt} \\ &+ \beta_7 WTOTRIPs_{jt} + \beta_8 law_{jt} + +\delta_9 FTA_{jt} \\ &+ \rho\sigma\eta_{jt} + \alpha_j + \gamma_t + \mu_{j,t}. \end{aligned} \tag{8}$$

Following Galushko (2012), Eq. (7) contains an additional variable *free* that is assumed to affect the extensive margin (the decision to export), but which is excluded from Eq. (8) on the assumption that it does not affect the intensive margin (how much to export).[2] The variable *free* is derived from the freedom-to-trade-internationally index from the *Economic Freedom of the World* database produced by the Fraser Institute (Gwartney et al., 2016). The index includes tariffs, regulatory trade barriers, black-market exchange rates, and controls on the movement of capital and people. A higher value for the index indicates that exporting to a specific country is easier. Prior to 2000, the index was calculated on a five-year basis (1985, 1990, 1995, 2000), where the missing years in the current study are extrapolated based on fitting a linear regression to the observed data.

The estimation results for (8) are reported in columns (1) to (5) of Table 3.[3] In terms of diagnostics, based on the Hausman test, estimation of the model using fixed rather than random effects is justified : $\chi^2 = 91.59$ and $\chi^2 = 117.62$ for Eqs. (1) and (3), respectively. The overall explanatory power of the model is satisfactory, the Wald χ^2 statistics all being statistically significant at the 1% level. In addition, the inverse Mill's ratio is statistically significant at the 10% level or higher, which indicates that the decision by U.S. firms to export seeds is not independent of how much to export, that is, application of the Heckman model is appropriate.

[2] Other exclusion variables, such as an index of legal structure and property rights, were tried in estimating (7), but they did not significantly improve the results.

[3] The results for the Probit equation (7) are reported in Supporting Information Appendix Table A4.

Table 3
Heckman selection model: Stage 2 estimates

Variables	*logseedIMP*				
	(1)	(2)	(3)	(4)	(5)
logGDPCap	1.699***	1.599***	1.566***	0.865**	1.511***
	(0.351)	(0.348)	(0.355)	(0.379)	(0.351)
logPop	1.888***	2.594***	2.824***	2.693***	2.106***
	(0.574)	(0.582)	(0.589)	(0.587)	(0.572)
loglCropProd	0.026	0.045	−0.020	0.082	0.034
	(0.160)	(0.159)	(0.158)	(0.159)	(0.159)
growGM	0.067	0.072	0.053	0.048	0.055
	(0.146)	(0.144)	(0.142)	(0.145)	(0.145)
UPOV	−0.751***	−1.354***	−1.484***	−9.934***	−0.965***
	(0.217)	(0.241)	(0.240)	(1.690)	(0.221)
UPOVhigh		2.230***	2.302***		
		(0.414)	(0.407)		
UPOVGDPpc				1.126***	
				(0.206)	
UPOVlaw					1.000***
					(0.208)
WTOTRIPs	0.792***	0.760***	0.708***	0.765***	0.754***
	(0.157)	(0.155)	(0.154)	(0.156)	(0.156)
law	0.311	0.234		0.182	−0.391*
	(0.189)	(0.188)		(0.190)	(0.238)
legal			−0.009		
			(0.210)		
FTA	0.172	0.204	0.191	0.171	0.186
	(0.203)	(0.200)	(0.198)	(0.203)	(0.202)
Constant	−30.23**	−4.539	−44.68***	−39.27***	−33.57***
	(10.08)	(10.40)	(10.33)	(10.40)	(10.02)
ρ	−0.491	−0.482	−0.387	−0.565	−0.519
σ	1.272	1.259	1.237	1.272	1.267
η (Mill's ratio)	−0.625**	−0.607**	−0.479*	−0.718***	−0.658**
	(0.270)	(0.267)	(0.264)	(0.263)	(0.267)
Wald χ^2	3,032.1***	3,124.8***	3,206.3***	3,094.6***	3,091.6***
Observations[a]	2,773	2,773	2,773	2,773	2,773
Censored	1,259	1,259	1,249[b]	1,259	1,259

Note: Country and time fixed effects included, but not reported.
[a]Number of observations reduced due to lagged variable and exclusion of zero trade flows.
[b]Number of observations reduced due to missing data for *legal* for eight countries in the panel.
*Standard errors in parentheses, and ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Focusing first on column (1) of Table 3, which excludes the interaction variable *UPOVhigh*, the gravity-type variables *logGDPCap*, and *logPop* both have estimated coefficients that are positive and statistically significant at the 1% level. The regression coefficient for *logGDPCap* is the conditional elasticity of seed imports with respect to GDP per capita, implying that each additional 1% increase in GDP per capita is estimated to raise seed imports by about 1.7%, given the other predictor variables in the model are held constant.[4] In addition, a 1% increase in an importing country's population is estimated to increase seed imports by 1.8%. The other gravity-type variables *loglCropProd*, and *FTA* have regression coefficients that are positive but statistically insignificant, as is the case of *growGM*. These results hold up over the other specifications reported in columns (2)–(5) of Table 3.

In terms of the impact of IPRs on seed trade, two conclusions can be drawn from the results shown in column (1) of Table 3: first, the estimated coefficient for *UPOV* membership is negative and statistically significant at the 1% level, that is, importing country membership of UPOV seems to discourage U.S. seed exports; and second, the estimated coefficient for *WTOTRIPs* is positive and statistically significant at the 1% level, that is, importing country membership of TRIPs encourages U.S. seed exports The regression coefficient for *law* also has the expected positive sign, but is not statistically significant. These results hold over the other specifications reported in columns (2)–(5) of Table 3.

The negative regression coefficient on *UPOV* is interesting, especially in light of the fact that of the 95 low-income countries in the sample, 32 are members of UPOV (see Supporting Information Appendix Tables A1 and A3). Therefore, further analysis of *UPOV* is reported in columns (2)–(5) of Table 3. In column (2), the results from interacting the variable *UPOV* with a dummy (0,1) measuring whether an importing country is high income, *UPOVhigh* are reported. The estimated regression coefficient for the latter is positive and that for the former is negative, with both statistically significant at the 1% level. These results indicate that, when the income level of an importing country is accounted for, membership of UPOV has a positive impact on U.S. seed exports to high-income countries ($\delta_5 + \delta_6 = 0.876$), but in the case of low-income countries, the IPR protection offered by UPOV membership does not encourage U.S. seed exports ($\delta_5 + \delta_6 = -1.354$).

As one robustness check for the latter result, an alternative variable, *legal*, was also used. This variable is taken from the *Economic Freedom of the World* database produced by the Fraser Institute, and is based on their index of legal structure and security of property rights in a country (Gwartney et al., 2016). As with *free*, prior to 2000, the index was calculated on a five-year basis (1985, 1990, 1995, 2000), where the missing years in the current study are extrapolated based on fitting a linear regression to the observed data. Importantly, *legal* is highly correlated with *law*, the correlation coefficient between them being 0.79 (see Supporting Information Appendix Table A2). The results in column (3) of Table 3 indicate that these results are robust to the choice of index reflecting the extent of IP protection. The remaining results reported in Table 3, columns (4) and (5), are all based on using the variable *law*.[5]

[4] The elasticity is a marginal effect conditional on countries importing a nonzero amount of U.S. seeds.

[5] As also noted by a reviewer, differing climate conditions between the United States and the sample of importing countries may matter for seed trade, a result supported by the earlier research of Galushko (2012). To evaluate this possibility, the absolute difference in average precipitation (temperature) between the United States and an importing country were tried as explanatory variables, neither having a statistically significant effect on U.S. seed exports. The possible explanation for this is twofold: first, this study uses aggregate U.S. seed export data compared to Galushko (2012) who uses disaggregated data for four crop-types; and, second, the country fixed effects are most likely already picking

The *UPOV* variable is also interacted with two other variables, *logGDPCap* and *law* as a means of checking on the robustness of the interaction term *UPOVhigh*, the results being reported in columns (4) and (5), respectively. In both cases the regression coefficient for *UPOV* remains negative and statistically significant at the 1% level, while the regression coefficients for *UPOVGDPpc* and *UPOVlaw* are both positive and statistically significant at the 1% level.[6] The interpretation of these results is as follows: at the mean level of GDP per capita, \$5,834, the effect of UPOV on U.S. seed exports is negative, while for GDP per capita in excess of \$6,783, the effect is positive. In the case of *law*, at its mean value of −0.6244, the effect of UPOV on U.S. seed exports is negative, but for values in excess of 0.95, the effect of UPOV on U.S. seed exports is positive. In summary, these results suggest that the impact of membership of UPOV on U.S. seed exports is positive for importing countries with higher GDP per capita and stronger enforcement of IPRs. Given the correlation coefficient between *GDPCap* and *law* of 0.78 (see Supporting Information Appendix Table A2), the most compelling explanation for the negative coefficient on the *UPOV* variable is that despite membership of UPOV, low-income countries in the sample tend to have weak enforcement of property rights, thereby undermining the willingness of the U.S. firms to export seeds to those countries.

Turning to interpretation of the positive regression coefficient for *WTOTRIPs*, and given the low correlation coefficient of 0.32 between UPOV and TRIPs (see Supporting Information Appendix Table A2), it appears that importing country membership of TRIPs has had an identifiably separate effect on U.S. seed exports to their membership of UPOV. This result can be rationalized as follows: first, there was a one-time effect of 23 high-income countries, who were already members of UPOV, signing on to TRIPs as they became members of the WTO in the mid 1990s; second, 25 low-income countries in joining TRIPs had implemented UPOV-like IPRs by the end of the sample period; and third, 33 countries that were not members of UPOV did sign TRIPs by the end of the sample period, thereby committing themselves to implementing UPOV-like IPRs. In other words, the positive impact of TRIPs on U.S. seed exports most likely represents the perceived benefits of harmonization of IPRs for seed innovations based on UPOV/PBRs and also the expectation that they will be enforced through the WTO dispute-settlement mechanism (Clancy and Moschini, 2017), along with the fact that TRIPs membership has been found to be correlated with stronger IP protection of plant varieties in importing countries (Campi and Nuvolari, 2015).

up climate differences between the United States and seed export destinations. These results are available on request from the authors.

[6] It should be noted that the signs on the estimated coefficients for *UPOV*, *UPOVhigh*, *UPOVGDPpc*, and *UPOVlaw* are robust to *WTOTRIPs* being excluded from the regressions reported in Table 3. These results are available on request from the authors.

Table 4
PPML model estimates

Variables	*seedIMP*				
	(1)	(2)	(3)	(4)	(5)
logGDPCap	2.474***	2.485***	2.890***	1.851**	2.331***
	(0.488)	(0.489)	(0.514)	(0.511)	(0.482)
logPop	0.913	1.337	3.149**	1.317	1.258
	(1.005)	(1.039)	(1.290)	(1.034)	(1.007)
loglCropProd	0.294	0.319	−0.058	0.318	0.343
	(0.246)	(0.245)	(0.285)	(0.247)	(0.244)
growGM	0.391***	0.389***	0.409***	0.366**	0.392***
	(0.143)	(0.143)	(0.148)	(0.144)	(0.142)
UPOV	−0.076	−0.902**	−1.233***	−6.632***	−0.549*
	(0.334)	(0.405)	(0.336)	(2.225)	(0.331)
UPOVhigh		1.969***	2.318***		
		(0.484)	(0.421)		
UPOVGDPpc				0.769***	
				(0.250)	
UPOVlaw					1.305***
					(0.264)
WTOTRIPs	0.497**	0.480**	0.454**	0.478***	0.445**
	(0.226)	(0.226)	(0.217)	(0.227)	(0.227)
law	1.330***	1.264***		1.279***	0.165
	(0.335)	(0.330)		(0.331)	(0.371)
legal			0.469		
			(0.348)		
FTA	−0.136	−0.158	−0.062	−0.169	−0.171
	(0.222)	(0.223)	(0.238)	(0.224)	(0.223)
R^2	0.78	0.78	0.75	0.78	0.78
Observations	3,053[a]	3,053[a]	2,753[b]	3,053[a]	3,053[a]

Notes: Country and time fixed effects included, but not reported.
[a]Number of observations reduced due to lagged variable, and one country is also dropped due to collinearity over sample time period.
[b]Number of observations reduced due to missing data for *legal* for eight countries in the panel.
*Robust standard errors in parentheses, and *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6.2. PPML model

As noted by Santos Silva and Tenreyro (2010, 2011b), there are convergence problems that are associated with using the Poisson command in Stata©. Therefore, their proposed methodology of pseudo-PML (PPML) is used to estimate the following equation:

$$\begin{aligned} seedIMP_{jt} = \exp[&\beta_1 logGDP_{jt}Cap + \beta_2 \log Pop \\ &+ \beta_3 logCropProd_{jt-1} + \beta_4 growGM_{jt} \\ &+ \beta_5 UPOV_{jt} + \beta_6 UPOVhigh_{jt} \\ &+ \beta_7 WTOTRIPs_{jt} + \beta_8 law_{jt} + \beta_9 FTA_{jt} \\ &+ \alpha_j + \gamma_t] + e_{jt}. \end{aligned} \quad (9)$$

The basic estimation results using fixed effects are reported in column (1) of Table 4.[7] The estimated coefficients for the

[7] It should be noted that the Hausman test is not applied to the PPML model, the random effects estimator not being suitable in a Poisson

gravity-type variables *logGDPCap*, *logPop*, and *llogCropProd* are all positive, the former being significant at the 1% level, suggesting for an importing country that: a 1% increase in its GDP per capita raises seed imports by 2.5%. For the other gravity-type variable, the regression coefficient for *FTA* is negative but not statistically significant. However, compared to the Heckman model results, the estimated coefficient for *growGM* is positive and statistically significant at the 1% level. The estimated coefficient implies that a country growing GM crops is expected to import 1.5 times more seed {exp(0.4)} than a country not growing GM crops. These results hold up over other specifications reported in columns (2)–(5).

In terms of the IPR variables, the regression coefficient for *UPOV* is negative and statistically significant at the 5% level when the interaction variable *UPOVhigh* is also entered, a result that holds up irrespective of whether *law* or *legal* is used as an index of the extent of IP protection—see columns (2) and (3) in Table 4. Qualitatively, these results are similar to those for the Heckman model: when the income level of an importing country is accounted for, membership of UPOV has a positive impact on U.S. seed exports to high-income countries ($\beta_5 + \beta_6 = 1.067$), but in the case of low-income countries, the IPR protection offered by UPOV membership does not encourage U.S. seed exports ($\beta_5 + \beta_6 = -0.902$).

Again as a robustness check for the interaction variable *UPOVhigh*, the *UPOV* variable is interacted with the variables *logGDPCap* and *law*, the results being reported in columns (4) and (5), respectively, of Table 4. In both cases, the regression coefficient for *UPOV* remains negative and statistically significant at the 1% and 10% level, respectively, while the regression coefficients for *UPOVGDPpc* and *UPOVlaw* are both positive and statistically significant at the 1% level. As with the Heckman model, these results can be interpreted as follows: at the mean level of GDP per capita, \$5,834, the effect of UPOV on U.S. seed exports is marginally positive. In the case of *law*, at its mean value of −0.6244, the effect of UPOV on U.S. seed exports is negative, but for values in excess of 0.42, the effect of UPOV on U.S. seed exports is positive. In summary, these results suggest that the impact of membership of UPOV on U.S. seed exports is positive for importing countries with higher GDP per capita and stronger enforcement of IPRs.[8]

Finally, the regression coefficient for *WTOTRIPs* is positive and statistically significant at the 5% level or higher across all of the models. There is also support for the hypothesis that better legal enforcement of IPRs has a positive impact on imports of U.S. seeds, the estimated coefficients for *law*, being positive in all cases, and statistically significant at the 1% level in three cases—columns (1), (2), and (4) in Table 4.

regression. See Santos Silva at http://www.statalist.org/forums/forum/general-stata-discussion/general/1343341-hausman-and-goodness-of-fit-for-xtpoisson

[8] Again, the signs on the estimated coefficients for *UPOV*, *UPOVhigh*, *UPOVGDPpc*, and *UPOVlaw* are robust to *WTOTRIPs* being excluded from the regressions reported in Table 4. These results are available on request from the authors.

7. Summary and conclusions

An important channel for cross-border transfer of technology embodied in seeds is international trade. Depending on the technology component, an exporter's decision to serve a particular market is more or less influenced by the extent of IP protection in that market. This is particularly true for the seed industry as plant breeding involves costly and lengthy investment, and seeds can either reproduce on their own or be imitated at low cost. Weak IPRs are likely to deter exporters from entering foreign markets. At the same time IPRs are a contentious issue between the North and South, the former arguing that stronger IPRs stimulate trade, investment and technology transfer, the latter concerned that IPRs negatively affect their firms and consumers.

To further investigate the role of IPRs in technology transfer through trade, the analysis presented in this article builds on earlier research on seed trade using a longer data set and focusing on field crop seeds, a category that includes seeds particularly susceptible to IPR infringement. Specifically, a gravity model was fitted to a panel of 134 countries importing seeds from the United States over the period 1985–2010, using both the Heckman and PML models with fixed effects. In contrast to the former methodology, the PML model has been shown to deal with both the problems of zero trade and heteroscedasticity, as well as the issue of country-specific heterogeneity, thereby reducing bias in econometric estimation. For that reason this is the preferred econometric method discussed in this article, along with the associated results.

Estimation of both Heckman and PML models over the sample period 1985–2010 provides some robust and statistically significant support for the hypothesis that IPRs, as measured through membership of UPOV, have positively affected U.S. seed exports to higher income countries with better legal enforcement of IPRs, but they have not positively affected exports to lower income countries with poor legal enforcement. At the same time, implementation of TRIPs has positively affected U.S. seed exports. The latter result most likely represents the perceived benefits of harmonization of IPRs for seed innovations and the expectation that they will be enforced through the WTO dispute-settlement mechanism, as well as the possibility that TRIPs membership has resulted in stronger IP protection of plant varieties.

These results stand in clear contrast to the earlier work of Yang and Woo (2006) and Eaton (2009) who found no evidence for importing country membership in international IPR agreements affecting seed trade, although it should be noted that while they both used export gravity models, their samples and the econometric methods applied were quite different. Yang and Woo (2006), using both panel and time-series econometric methods, focused on the impact of UPOV and TRIPs membership for a sample of 60 countries over the period 1990–2000, while Eaton (2009), using a fixed-effects quantile regression model, focused on the effect of UPOV for a sample of 70 countries importing seeds from both United States and 10 EU countries.

The results reported in the current article do however partially reinforce the previous findings of Galushko (2012), although again the sample and methodologies are different. Galushko (2012) using the Heckman selection methodology applied to a gravity model without fixed effects, focused on U.S. seed exports to a total of 137 countries over the period 1995–2005, where different crops (open-pollinated, GM, and hybrid) were categorized into four specific groups. Across the crop categories, she did find some evidence that UPOV had a negative effect on U.S. seed exports to low-income countries in her sample, while membership of TRIPs had a positive effect on seed exports, and enforcement of IPRs mattered. In contrast, the current article applies both the Heckman selection and PML methodologies with appropriate fixed effects to a similar-sized sample of countries over a longer time period. Use of the PML methodology, which is now typically preferred in estimation of the gravity model (Anderson and Yotov, 2010b), provides robust statistical evidence for IPRs having a mixed effect on U.S. seed exports.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting Information
Appendix Table A1: Sample countries
Appendix Table A2: Correlation Matrix
Appendix Table A3: UPOV member countries
Appendix Table A4: Heckman selection model: Stage 1 estimates