Multinational Technology Diffusion in Agriculture

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Abstract: This paper presents data on international technology diffusion of agricultural biotechnology. Patent family data, which identify related intellectual property in different countries with the same owner, represents technology flows between countries. Technology flows occur mostly between developed countries, and are similar for different types of entities (private, non-profit and university, government) that seek patent protection abroad. Technology diffusion through patent families is a significant predictor of international trade flows, which is consistent with several different models of trade.

1. Introduction

Performers of research and development seek returns on their investments, but a widely noted aspect of R&D is that many of the economic benefits redound to others. Spillovers accrue to consumers, industry competitors, and upstream or downstream users of R&D results. Similarly, benefits of R&D accrue not just within the country in which they take place, but they also create positive international effects on productivity. The growing prominence of multinational firms in agricultural R&D creates a potential connection between these different influences. This study gathers several sources of data on research activities by multinational firms pursuing research in agricultural biotechnology from 1976-2000 and examines patterns of international technology diffusion in greater detail. In particular, this study examines the relative significance of trade and intellectual property channels for technology diffusion.

Turning first to intellectual property, this paper examines one international geographic aspect of patents that often goes overlooked in the literature on patents as indicators of R&D and technological change. Although patents are national documents that do not extend beyond national borders, it is possible to determine when patent holders obtain patent rights on the same technology in different countries. These "patent families" of closely related intellectual property provide a tool to describe how companies protect technologies in other countries.

Economic studies have referenced patent families for some time: Pavitt (1985) cites data on patent families collected by Grevink and Kronz (1979), and Lanjouw et al (1996) use patent family size to weight patent value estimates based on patent renewal information. Eaton and Kortum (1996) discuss size of family membership in a model of trade and technology diffusion, but do not explicitly include patent family data in their analysis. This paper describes the extent of technology diffusion through patent families and presents some preliminary analyses.

The other channel through which technology can diffuse internationally is international trade. The Ricardian insight into trade is one possible characterization: technology leading to specialization in comparative advantage can increase productivity in another country even without direct diffusion of technology. The Heckscher-Ohlin model of trade emphasizes the role of factors of production, and technological change can alter terms of trade by affecting factor productivity and therefore relative scarcity. More recent models of trade (i.e. "New Trade Theory") emphasize increasing returns to scale, differentiated products, and intraindustry trade. Later Interpretation of the interaction between international technology diffusion and agricultural trade considers these different modalities of trade.

2. Data

This paper examines the technological diffusion of agricultural biotechnology through the latter part of the 20th century. Agricultural biotechnology is a good subject for the study of technological diffusion for several reasons. Despite some common elements with conventional agricultural R&D, agricultural biotechnology represents a distinctly new set of technologies that can be traced from their inception. Moreover, agricultural biotechnology has had a profound influence on agricultural production in a relatively short span, accounting for more than half of all crop acreage since their commercial introduction in the 1990s (James, 2008), and with important impacts on animal agriculture as well. Agricultural biotechnology also features significant international research participation by firms, non-profits, and public sector research agencies. Another advantage is the readily available data on agricultural biotechnology patents in the publicly available Agricultural Biotechnology Intellectual Property (ABIP) Database (USDA, 2004). ABIP identifies more than 11,000 U.S. patents related to agricultural biotechnology awarded to U.S. and non-U.S. entities between 1976-2000. The ABIP data also include information about patent ownership through 2002, which is helpful in analyzing research by different types of organizations and the effects of mergers and acquisitions on firm intellectual property portfolios.

Data on patent families are drawn primarily from Patent Cooperation Treaty (PCT) filings. The PCT – which was concluded in 1970 and now has more than 130 signatory nations – facilitates the process of applying for patent protection in other countries by allowing inventors to file a single application and designate multiple countries in which they will eventually seek patent protection. This establishes inventorship rights in a timely way and promotes invention disclosure and diffusion, but postpones eventual costs for patent translation, application and legal fees. PCT filings are therefore a primary source of information about the speed and geographical spread of technology diffusion. By tracing records that share a common early application (or "priority document"), PCT filings also provide other information that allows researchers to identify "patent families": clusters of closely related intellectual property in multiple countries with the same inventor or assignee. The Delphion Patent Research service offered by Thomson Reuters indexes patent priority documents from the International Patent Documentation Center (INPADOC) of the World Intellectual Property Organization (WIPO), and uses them to identify patent families by priority document. The 11,073 U.S. patents identified in ABIP matched with 195,980 family member patents issued by 74 national and regional patent authorities.

A readily observable fact about PCT families for agricultural biotechnology patents in the U.S. is that patent protection is sought mostly by inventors in developed countries, and diffusion of patents is primarily directed toward other developed countries. (See Table 1.) For ABIP patents assigned to U.S. entities (firms, non-profits, and governments), the top 10 destinations where protection was sought were all developed countries that represented 72.1% of non-U.S.

patent family members; the 25 countries with the highest per capita GDP accounted for more than 86% of patent family members (including filings with WIPO and the European Patent Office). Among U.S. agricultural biotechnology patents assigned to non-U.S. entities, the top 10 sources of patented technologies were all developed countries accounting for 91.7% of the total. Differences in the way national patent laws and patent authorities interpret the "unity of invention" doctrine can influence patent family size in particular countries. For instance, a U.S. patent with several independent claims relating to the same invention might be filed as several stand-alone patents, especially in Japan and the Nordic countries. For this reason, panel data estimation with country-specific effects offers advantages for the study of patent families.

Two ways to measure the magnitude of technology diffusion through patent families are the number of patents within a family and the number of countries. U.S. entities sought patent protection on average in 7.11 countries (standard deviation: 6.22), and the average patent family had 17.80 members (standard deviation: 35.35). (See Table 2.) The distribution of family size by either of these measures is skewed: a significant number of patent families assigned to both U.S. and non-U.S. entities contain only one patent, and an even larger number of families have no non-U.S. family members. (See Figures 1 and 2.) Perhaps the large number of singleton and U.S.-only patent families should be unsurprising for some U.S. entities: not every patent justifies the expense of foreign patenting, even in the emerging and internationally competitive area of agricultural biotechnology. However, it is nonetheless surprising to observe so many singleton and U.S.-only patent families assigned to non-U.S. entities.

To relate ABIP patents and their family members more specifically to agriculture, they were matched against a dataset prepared using the OECD Technology Concordance, described by Johnson (2002). The OECD Technology Concordance estimates the likely industry of manufacture (IOM) and sector of use (SOU) for a patent based on its classification according to International Patent Classifications (IPC). Through a cooperative research agreement, Johnson prepared a database of all INPADOC patents[1] with an estimated agricultural SOU greater than 1%. Nearly all (99.75%) ABIP patents were not affected by the minimum agricultural SOU value and were included in the database. The median likelihood that an ABIP patent's IPC profile indicates agricultural SOU is 4.8%; the mean likelihood of agricultural SOU is 16.2%. Of the 195,980 ABIP family members identified by Delphion, only 51,274 were assigned an agricultural SOU. Reasons for attrition in the data merge were incomplete Delphion information (34,944), patent awards from the countries excluded from the analysis in the note above (14,635), an unknown number of family members with an agricultural SOU less than 1% (likely small because of their connection to ABIP priority documents), and other unexplained reasons. For the family members of the ABIP patents – which might vary in their IPC profile to comply with national patent office requirements – the median likelihood of agricultural SOU is 4.2%; the mean is 7.6%.

Delphion also provided data for forward patent citations, patents issued subsequently that refer back to a given patent. Patent citations are a commonly used indicator of patent value. Forward citations, i.e. subsequently issued patents that cite a patent in question, are evidence that a patent has relevance for subsequent technologies.[2] Empirically, the number of forward citations a patent has is a discrete count variable. Also, patents of equal influence or quality that issue in later sample years are likely to have unequal forward citations because of truncation. To address both of these problems, this paper uses an adjusted measure of forward citations. Observed

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[1] Countries excluded from this analysis because of inability to distinguish patent applications from patent awards were: Argentina, Belgium, Colombia, Costa Rica, German Democratic Republic, Ecuador, Spain, Georgia, Guatemala, Israel, Luxemburg, Mexico, Malawi, Nicaragua, New Zealand, Singapore, and Thailand.

forward citations per patent are divided by the expected number of forward citations conditional on time elapsed since patent grant, as estimated by a negative binomial regression for the sample of ABIP patents. The negative binomial regression accommodated overdispersion in the distribution, rejecting the null that mean equaled variance (as in a Poisson distribution).

To estimate the trade component of this research, this paper uses trade aggregates from the USDA Foreign Agriculture Service (USDA, 2008) converted to constant (1990) dollars using the BEA GDP deflator (Department of Commerce, 2009). Information about international agricultural value added and share of GDP were obtained from the United Nations (2008). Estimates of distances between countries were obtained from Hengeveld (1998).

3. International Diffusion of Technology in a Trade Context

To incorporate the new data on technology diffusion, this paper begins with the simple model of trade known as the gravity model, in which trade flows (exports plus imports) between countries *i* and *j* (F_{ij}) are a function of the respective economic "masses" of the two countries (M_i,M_j), their distance apart (D_{ij}), and a constant (G):

$$F_{ij}=GM_iM_j(D_{ij})^{-1} \quad (1)$$

Taking logs of both sides, an empirical estimation of equation (1) with random effects takes the form:

$$\ln F_{itj}= \beta_0+\beta_1\ln(M_{it})+ \beta_2\ln(M_{jt})+ \beta_3 \ln(D_{ijt})+\mu_j+ \varepsilon_{it} \quad (2)$$

To estimate agricultural trade flows between the U.S. and sample countries with family members of U.S. agricultural biotechnology patents, the measurement for economic mass is real agricultural value added. The constant term subsumes both G and M_{it} as country *i* is the United

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[2] The most frequently cited patent in the ABIP database is for the polymerase chain reaction, a widely used

States in every period. The estimation period spans the years for which trade data were readily obtainable (1989-2007), and distances are the minimum sea shipping distances between the U.S. and country *j*.

Table 3 presents the results of a GLS random-effects model to estimate equation (2). The basic gravity model estimates trade flows with predicted signs and statistically significant coefficients. The relatively high goodness-of-fit for a parsimonious model is a reason why the gravity model of trade good point of departure for further analysis.

To estimate whether technology flows (T_{ijt}) have a correlation with trade, this paper constructs a measurement of technology flows to another country using the number of patent family members of U.S. patents in that country plus the number of U.S. patents assigned to entities based in that country. Supposing for now that technology and trade are exogenous, GLS estimation of a random effects model provides consistent coefficient estimates of the following equation:

$$(3) \qquad \ln F_{itj} = \beta_0 + \beta_1 \ln(M_{it}) + \beta_2 \ln(M_{jt}) + \beta_3 \ln(D_{ijt}) + \beta_4 \ln(T_{ijt}) + \mu_i + \varepsilon_{it}$$

Table 4 presents regression results estimating equation (3) under two specifications of T_{ijt}. Under the first specification, T_{ijt} equals the number of patents issued in time period *t*. The second specification of T_{ijt} equals the number of patents issuing between 1976 and time period *t*. This cumulative measure of technology flows is preferable because it reflects earlier technological advances within countries and exchange between countries. This estimation is equivalent to a "stock of knowledge" model (with no depreciation), which better models the time required to commercialize patented technology. Since the estimation period begins in 1989, several years after the first patents are recorded in 1976, the cumulative measure of T_{ijt} already

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technique to make copies of DNA that is fundamental to biotechnology research.

quantifies significant technology flows. Another reason to prefer the cumulative measure over the actual measure is that country-year observations with no issued patents are excluded because their logarithm is not defined.

In the exogenous model, the correlation between technology flows and trade flows is positive and significantly different from zero. The log specification means that coefficients are elasticities and therefore that their respective magnitudes can be compared. Under the first (non-cumulative) specification of technology flows, the technology coefficient is quite small in size (0.03) and the coefficients on economic magnitude and physical distance components of the gravity model are essentially unchanged from the estimation results of equation (2). Under the second (cumulative) specification of technology flows, the magnitude of the technology coefficient is larger but still small relative to the other components (0.08). The coefficient on agricultural value added is reduced under the second specification, but the coefficient on distance is statistically unchanged.

The positive correlation between technology flows and trade flows is consistent with several theories of trade. For instance, R&D that enhances comparative advantage of export goods in any country would increase bilateral trade flows while firms would be observed producing with the technology or licensing it in other countries. Alternately, Keller (2004, p 75) surveys several models of diffusion in which technology is embodied in improved intermediate goods. In these models, trade flows of intermediate goods are the primary means through which multinational firms can benefit from successful R&D; technology flows are then synonymous with (some fraction of) trade flows. In these cases, intellectual property protection would still be observed to prevent imitation and preserve market share abroad. Another possibility is the case of differentiated goods produced with increasing returns to scale (for example Krugman, 1980;

1981). If technology tends to differentiate goods rather than improve them, but returns to technology arise from satisfying demand for increased variety, then the country of production is less important than consolidating production in a specific country to take advantage of returns to scale. If some fraction of technologies are ultimately produced in other countries, the volume of trade should rise directly with technology. Davis (1995) synthesizes a model of differentiated products in which arbitrarily small technology differences can radically shift production between intraindustry and interindustry trade (either between goods or between sectors); this model generalizes the association between trade and technology in differentiated goods beyond increasing returns technology.

Other models of trade are less amenable to the positive correlation estimated by the exogenous specification. The Heckscher-Ohlin model predicts trade in goods for which inputs are more abundant. Technology that enhances the productivity of a scarce input in the same country could reduce trade without diffusion of the technology. Ethier and Markusen (1996) describe a model of multinational technology firms with incomplete licensing agreements, where possible outcomes include failure of technology diffusion or technology diffusion through foreign direct investment and production. These scenarios could then be consistent with a negative correlation between technology and trade, especially if the latter scenario involves foreign production mainly to satisfy foreign demand (reducing exports to that country).

A difficulty posed by the exogenous specification of technology impact on trade flows specified in equation (3) is the possibility that technology flows influence trade flows. If trade flows influence technology production and diffusion, then the endogenous influence of trade on technology can result in biased, inconsistent estimates of equation (3). Under the assumption that R&D processes and their resulting technologies are essentially random, this does not pose an estimation problem; but under the more plausible assumption that firms direct research towards projects with higher marginal value (as in Rausser and Small, 2000), then the significance of R&D and new technologies in trade requires additional empirical estimation.

To improve on estimation of the exogenous model, Table 5 presents a panel data-instrumental variable estimation, with the natural logarithm of the agricultural share of value added serving as an instrument for technology flows. Agricultural share of value added is significantly (negatively) correlated with technology flows, as suggested by the technology flows between developed countries reported in Table 1. The usefulness of agricultural share of value added as an instrumental variable lies in its ability to indicate the appropriateness of a technology – and therefore its need for patent protection – in another country. In developed countries in North America and Europe, where agricultural value added is quite high but its share of total value added is low (typically between 1-3 percent), similar capital- and input-intensive systems provide the most opportunity for commercialization of technology flows. Yet agricultural share of total value added should be exogenous to trade flows, which are determined by relative prices, commodity types, seasonal availability, and other factors.

The instrumental variable regressions in Table 5 indicate a stronger influence of technology flows on trade. Both of the instrumented specifications of technology flows indicate technology elasticities of trade that are 3.7 (non-cumulative) and 7.4 (cumulative) times larger than those estimated in the exogenous model. The effect of distance is somewhat smaller under the endogenous technology estimation, but still large, negative, and statistically significant. The relative importance of economic magnitude (real agricultural value added) is reduced, and in the cumulative specification of technology it is not significantly different from zero. Although the cumulative measure of technology change is preferred for reasons discussed above, the diminution of the agricultural added value coefficient under this specification is somewhat troubling. Aside from this estimation issue, these results generally reinforce the earlier finding that technology flows are a significant determinant of agricultural trade.

4. Conclusions

This paper presents new data on international patenting in the field of agricultural biotechnology, and uses it to describe a possible channel through which technology affects agricultural trade flows. The data show that most patent families — patents in different countries on related technology assigned to the same entity — both originate in and expand to developed countries. Also, patent families assigned to different entity types (firms, non-profits and universities, governments) exhibit similar patterns in the both family size and distribution. This is true even though different entity types vary in the overall level of patents they obtain.

Estimation of a model of trade patent family diffusion is consistent with several models of international trade and technology flows. Additional specification of a model and acquisition of complementary data – especially on technology embodied in intermediate goods and foreign direct investment – would likely be necessary to discriminate among the possible rationales for trade and roles for technology. These preliminary findings demonstrate the potential utility of patent family data as a mechanism for technology diffusion, particularly at the microeconomic level. Many of the empirical models of technology diffusion reviewed by Keller (2004) describe spillovers in terms of their aggregate effects on total factor productivity. Further research could improve empirical microeconomic foundations of technology diffusion.

The patent families in this paper were related to U.S. agricultural biotechnology patents issued between 1976-2000. This raises concerns about using agricultural biotechnology to stand in for agricultural technology generally. To the extent that agricultural biotechnology represented an advanced technology that moves in parallel with other technological advances at the national level, agricultural biotechnology patents is an appropriate measure. However, to the extent that R&D occurs in areas other than biotechnology, estimations in this paper might be biased or inconsistent. Indeed, it might be possible to examine issues related to differential rates of adoption of genetically engineered crops by examining variation in how firms research and patent (although agricultural biotechnology is not restricted to genetic engineering). Additionally, a lacuna in this data set is the set of agricultural biotechnology patents issued to non-U.S. countries for which no U.S patent protection was sought, although this gap may be relatively minor.

Table 1. Destination and Source Countries for U.S. Agricultural Biotechnology Patents, 1976-2000.

		Destinations of US-Originated Patents			*US Patents from Non-US Sources*		
2-Letter Abbrev.	*Country*	*Patents*	*Share of Total (n=102,227)*	*Mean Probability of Ag SOU*	*Patents*	*Share of Total (n=3,523)*	*Mean Probability of Ag SOU*
EP	European Patent Office	15,872	15.5%	0.201	-	0.0%	0.070
JP	Japan	14,345	14.0%	0.152	934	26.5%	0.065
AU	Australia	9,728	9.5%	0.204	94	2.7%	0.076
DE	Germany	8,250	8.1%	0.195	575	16.3%	0.019
CA	Canada	6,186	6.1%	0.198	241	6.8%	0.080
WO	WIPO	5,987	5.9%	0.220	-	0.0%	*
ES	Spain	3,733	3.7%	0.167	13	0.4%	*
AT	Austria	3,530	3.5%	0.192	3	0.1%	*
DK	Denmark	3,335	3.3%	0.159	123	3.5%	0.062
IL	Israel	2,548	2.5%	0.175	42	1.2%	*
GB	United Kingdom	2,432	2.4%	0.156	370	10.5%	0.081
FI	Finland	1,954	1.9%	0.167	36	1.0%	0.055
HU	Hungary	1,837	1.8%	0.203	27	0.8%	0.088
NO	Norway	1,773	1.7%	0.168	7	0.2%	0.054
CN	China	1,640	1.6%	0.239	6	0.2%	*
ZA	South Africa	1,593	1.6%	0.166	5	0.1%	0.082
NZ	New Zealand	1,478	1.4%	0.192	18	0.5%	*
BR	Brazil	1,212	1.2%	0.207	2	0.1%	*
FR	France	1,069	1.0%	0.159	297	8.4%	0.046
KR	South Korea	860	0.8%	0.196	25	0.7%	0.059
IE	Ireland	777	0.8%	0.163	3	0.1%	0.064
GR	Greece	764	0.7%	0.171	4	0.1%	0.070
IT	Italy	510	0.5%	0.178	23	0.7%	0.088
NL	Netherlands	475	0.5%	0.158	246	7.0%	0.068
SE	Sweden	432	0.4%	0.136	21	0.6%	0.055
MX	Mexico	425	0.4%	0.205	2	0.1%	*
BG	Bulgaria	334	0.3%	0.222	1	0.0%	*
RU	Russia	330	0.3%	0.260	4	0.1%	0.096
BE	Belgium	279	0.3%	0.138	77	2.2%	*
HK	Hong Kong	278	0.3%	0.183	2	0.1%	*
AR	Argentina	274	0.3%	0.195	1	0.0%	*
CH	Switzerland	202	0.2%	0.154	272	7.7%	*
SG	Singapore	201	0.2%	0.194	1	0.0%	*
TW	Taiwan	118	0.1%	0.284	18	0.5%	0.054
	Total	94,761	92.7%		3,493	99.1%	

Sources: ABIP(2004); Delphion(2008); Johnson (2002)   * Not available

Table 2. Family size of U.S. agricultural biotechnology patents by assignee type, 1976-2000.

Type	*Patents*	*Number of patents*		*Number of countries*	
		Mean	*S.D.*	*Mean*	*S.D.*
US firm	4,223	17.71	35.89	7.11	6.24
US non-profit	2,247	18.11	35.52	7.11	6.23
US government	377	16.93	27.32	7.20	5.97
Non-US firm	2,973	17.70	33.33	6.91	5.91
Non-US non-profit	392	19.16	40.44	7.65	6.35
Non-US government	345	14.88	17.26	6.85	5.38
All US	6,847	17.80	35.35	7.11	6.22
All non-US	3,710	17.59	33.03	6.99	5.91
Unassigned/other	516	18.13	30.12	7.40	6.39
Total	11,073	17.75	34.36	7.08	6.13

Sources: ABIP(2004); Delphion(2008)

Table 3. Gravity Model of Trade.

Dependent Variable: Agricultural Exports + Imports ($1990 US)

Variable	*Coefficient (std. error)*	*z-statistic (p-value)*
Ag. value added, $1990 US (ln)	**.3907** (.0866)	4.51 (0.000)
Distance (km)	**-1.277** (.3653)	-3.50 (0.000)
Constant	**20.98** (3.335)	6.25 (0.000)
	Countries=29 Obs./country=18 Total obs.=522 Wald $\chi^2(2)$=33.03 p-value=0.000	R^2: Within=0.0021 Between=0.5681 Overall=0.5475

Countries:AT, AU, BE, BG, CA, CH, CN, DE, DK, ES, FI, FR, GB, GR, HU, IE, IL, IN, IS, IT, JP, KE, KR, MX, NL, NO, NZ, RU, SE, TW, ZA.

Table 4. Gravity Model of Trade with Exogenous Technology Flows.

Dependent Variable: Agricultural Exports + Imports ($1990 US)

	(1)		*(2)*	
Variable	***Coefficient (std. error)***	***z-statistic (p-value)***	***Coefficient (std. error)***	***z-statistic (p-value)***
Ag. value added, $1990 US (ln)	0.4089 (0.0935)	4.37 (0.000)	0.3056 (0.0877)	3.48 (0.000)
Distance (km)	-1.230 (0.3351)	-3.67 (0.000)	-1.237 (0.3373)	-3.67 (0.000)
Technology flow	0.0356 (0.0173)	2.06 (0.040)		
Technology flow, cumulative			0.0856 (0.0206)	4.16 (0.000)
Constant	20.19 (3.113)	6.49 (0.000)	20.82 (3.108)	6.70 (0.000)
	Countries=29 Obs./country=11.7 Total obs.=338 Wald $\chi^2(3)$=43.07 p-value=0.00	R^2: Within=0.0086 Between=0.6074 Overall=0.5944	Countries=29 Obs./country=18 Total obs.=522 Wald $\chi^2(3)$=57.09 p-value=0.00	R^2: Within=0.0311 Between=0.5854 Overall=0.5657

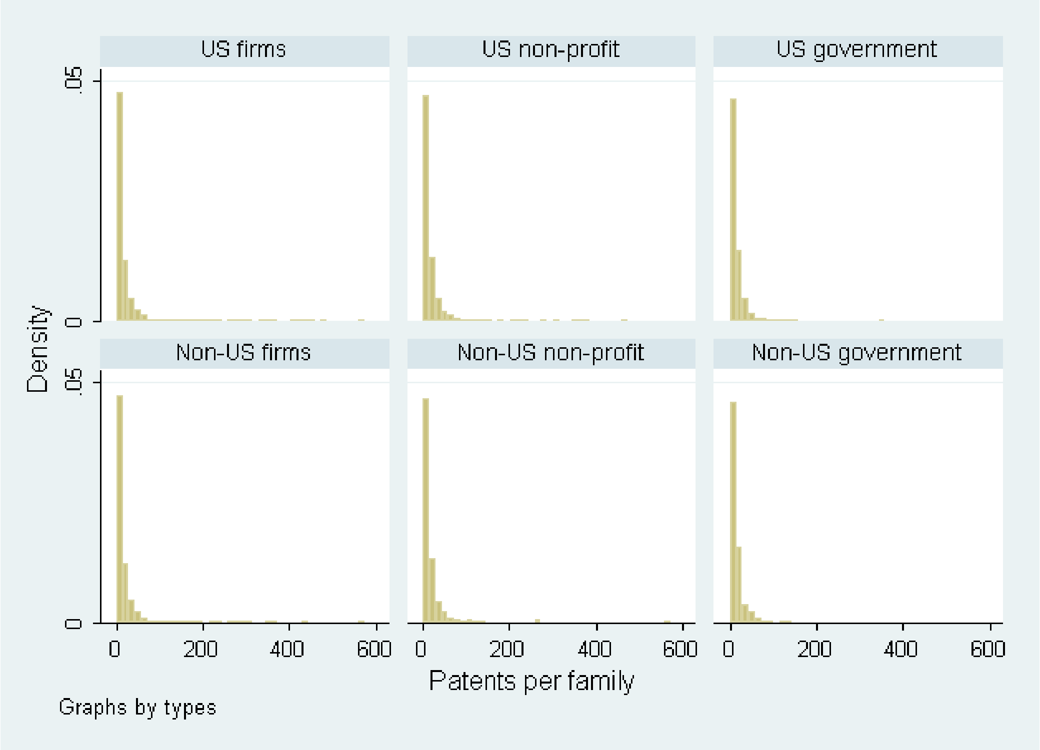
Countries:AT, AU, BE, BG, CA, CH, CN, DE, DK, ES, FI, FR, GB, GR, HU, IE, IL, IN, IS, IT, JP, KE, KR, MX, NL, NO, NZ, RU, SE, TW, ZA.

Table 5. Gravity Model of Trade with Endogenous Technology Flows.

Dependent Variable: Agricultural Exports + Imports ($1990 US)
Instrument for Technology Flows: Ag. Share of Total Value Added (ln)

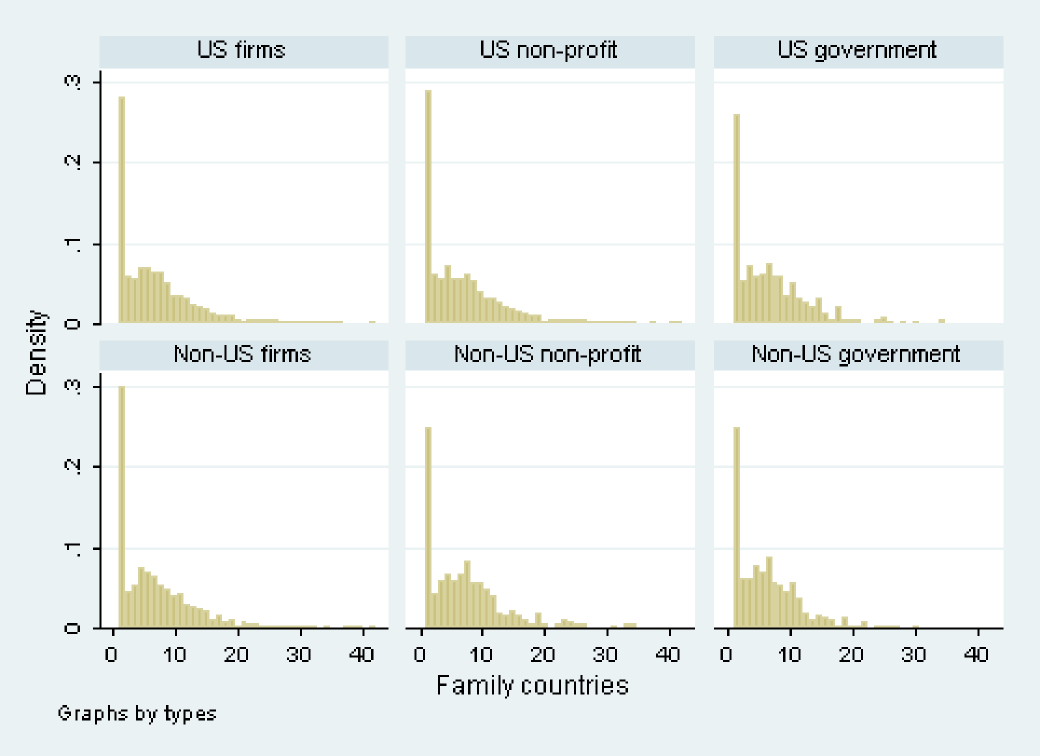
	(1)		(2)	
Variable	**Coefficient (std. error)**	**z-statistic (p-value)**	**Coefficient (std. error)**	**z-statistic (p-value)**
Ag. value added, $1990 US (ln)	0.2245 (0.1141)	1.97 (0.049)	0.0632 (0.0992)	0.64 (0.524)
Distance (km)	-1.129 (0.3724)	-3.03 (0.002)	-1.138 (0.3512)	-3.24 (0.001)
Technology flow	0.2233 (0.0421)	5.29 (0.000)		
Technology flow, cumulative			0.2983 (0.0329)	9.07 (0.000)
Constant	20.13 (3.463)	5.81 (0.000)	20.71 (3.244)	6.38 (0.000)
	Countries=29 Obs./country=11.7 Total obs.=338 Wald $\chi^2(3)$=43.07 p-value=0.00	R^2: Within=0.0187 Between=0.5913 Overall=0.5405	Countries=29 Obs./country=18 Total obs.=522 Wald $\chi^2(3)$=119.8 p-value=0.00	R^2: Within=0.0448 Between=0.4568 Overall=0.4277

Figure 1. Family size (patents) of U.S. agricultural biotechnology patents, 1976-2000.



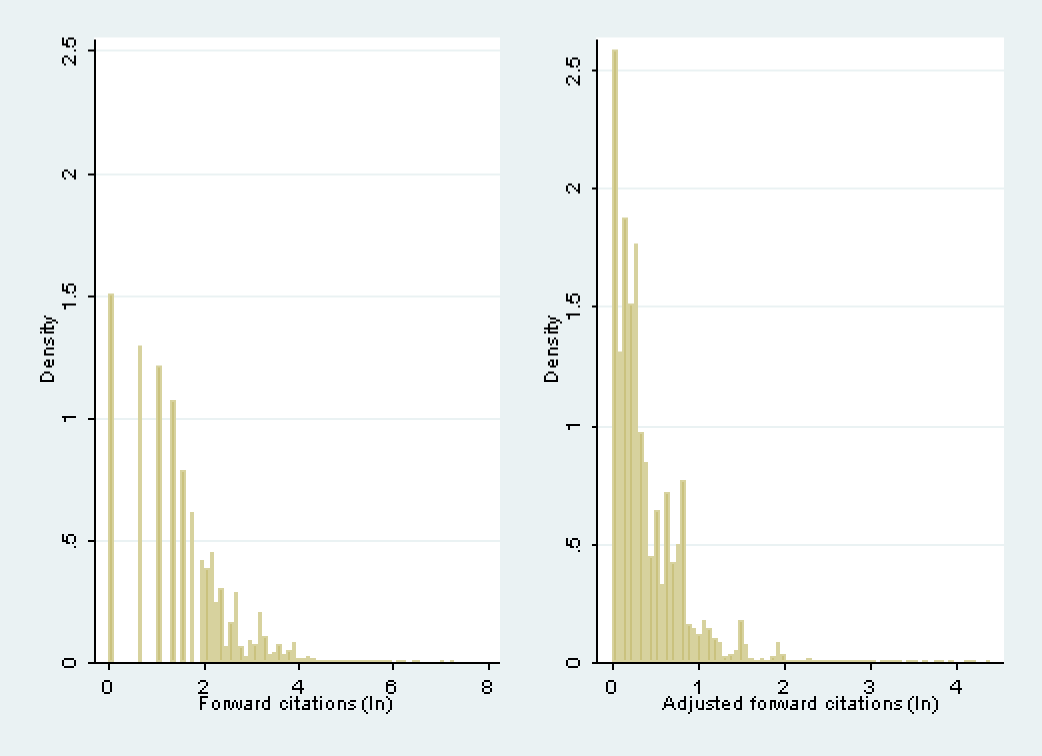
Sources: ABIP (2004); Delphion (2008)

Figure 2. Family size (countries) of U.S. agricultural biotechnology patents, 1976-2000.



Sources: ABIP(2004); Delphion(2008)

Figure 3. Distribution of unadjusted and adjusted forward citations to U.S. agricultural biotechnology patents, 1976-2000.



References

Davis, Donald R. (1995). “Intra-industry trade: A Heckscher-Ohlin-Ricardo approach.” *Journal of International Economics* 39(2): 201-226.

Department of Commerce Bureau of Economic Analysis (2009). Gross domestic product: implicit price deflator. Accessed at < http://research.stlouisfed.org/fred2/data/GDPDEF.txt> on March 25, 2009.

Eaton, Jonathan and Samuel Kortum (1996). “Trade in ideas: patenting and productivity in the OECD.” *Journal of International Economics* 40: 251-278.

Ethier, Wilfred and James R. Markusen (1996). “Multinational firms, technology diffusion and trade.” *Journal of International Economics* 41:1-28.

Grevink, H. and H. Kronz. (1979) “Evolution of patent filing activities in the EEC.” Commission of the European Communities, EUR 6574 e.

Hengeveld, W.A.B. (1999). “World Distance Tables, 1948-1974.” ICPSR 6152. Ann Arbor, MI: Interuniversity Consortium for Political and Social Research.

James, Clive. 2008. Global Status of Commercialized Biotech/GM Crops: 2008. ISAAA Brief No. 39. ISAAA: Ithaca, NY.

Keller, Wolfgang (2004) “International technology diffusion.” *Journal of Economic Literature* 42(3): 752-782.

Krugman, Paul (1980). “Scale economies, product differentiation, and pattern of trade.” *American Economic Review* 70: 950–959.

Krugman, Paul (1981). “Intraindustry specialization and gains from trade.”*Journal of Political Economy*,89(5): 959-973.

Johnson, Daniel K.N. (2002). "The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use," OECD Science, Technology and Industry Working Papers 2002/5, OECD Directorate for Science, Technology and Industry.

Lanjouw, Jean, Ariel Pakes, and Jonathan Putnam (1996). “How to count patents and value intellectual property: The uses of patent renewal and application data.” *Journal of Industrial Economics* 46(4): 405-432.

Pavitt, K. (1985). “Patent statistics as indicators of innovative activities: Possibilities and problems.” *Scientometrics* 7(1-2): 77-99.

Rausser, Gordon C. and Arthur A. Small (2000). “Valuing research leads: bioprospecting and the conservation of genetic resources.” *Journal of Political Economy* 108(1):173-206.

USDA Economic Research Service (2004). Agricultural Biotechnology Intellectual Property database. Accessed at www.ers.usda.gov/data/agbiotechip> on December 1, 2008.

USDA Foreign Agricultural Service (2008). U.S Trade Foreign Exports/Imports – FATUS Commodity Aggregations. Accessed at <http://www.fas.usda.gov/USTrade/USTExFatus.asp?QI= >/ <http://www.fas.usda.gov/USTrade/USTImFatus.asp?QI=> on March 25,2009.

United Nations Department of Economic and Social Affairs (2008). National Accounts Main Aggregates database. Accessed at <http://unstats.un.org/unsd/snaama/selectionbasicFast.asp> on March 20, 2009.