Changing patterns in the international movement of crop genetic material: An analysis of global policy drivers and potential consequences

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Abstract:

During the last several years, a series of important policy changes affecting genetic resource conservation, use, and exchange have entered into force. These policy changes will likely affect investment choices made by the international research-for-development community - choices that influence scientific collaboration and cooperation nationally, regionally and internationally. Specifically, these policy changes may introduce new institutional constraints on the use of genetic resources, with potentially long-lasting influence on research priority-setting and collaboration strategies. This paper provides a novel characterization of the changing landscape governing international germplasm exchanges. Emphasis is placed on culling evidence from historical trends, networks, and econometric analysis to better understand how national regulatory changes associated with the Convention on Biological Diversity (CBD) of 1993 and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) of 2004 affected the movement of genetic resources and lessons to be drawn to understand the potential effects of the Nagoya Protocol which entered into force beginning 2014.

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JEL Codes: Q18, Q55

#445

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Abstract

During the last several years, a series of important policy changes affecting genetic resource conservation, use, and exchange have entered into force. These policy changes will likely affect investment choices made by the international research-for-development community - choices that influence scientific collaboration and cooperation nationally, regionally and internationally. Specifically, these policy changes may introduce new institutional constraints on the use of genetic resources, with potentially long-lasting influence on research priority-setting and collaboration strategies. This paper provides a novel characterization of the changing landscape governing international germplasm exchanges. Emphasis is placed on culling evidence from historical trends, networks, and econometric analysis to better understand how national regulatory changes associated with the Convention on Biological Diversity (CBD) of 1993 and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) of 2004 affected the movement of genetic resources and lessons to be drawn to understand the potential effects of the Nagoya Protocol which entered into force beginning 2014.

Keywords: CBD, genetic resources policy, genebanks, germplasm, international agricultural research, ITPGRFA, Nagoya Protocol, plant breeding.

JELclass: Q16, Q18, Q55, Q57

1 Introduction

On October 12, 2014, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits entered into force as a follow-on to the 1993 Convention on Biological Diversity (CBD). The protocol creates an access and benefit-sharing (ABS) rights regime that seeks to improve global, national, and local governance over the use and exchange of genetic resources for food and agriculture (GRFA). The highlight of this regime are provisions that describe how benefits derived from genetic resources are shared among countries and communities that have contributed to their conservation and use. When viewed alongside other global agreements and national policies that address the management of GRFA, the Nagoya Protocol is the latest in a series of changes that will likely influence investment choices made in the international agricultural research-for-development community. The nature, direction, and magnitude of these choices is currently a topic of muted debate despite their potential impact on scientific collaboration and cooperation nationally, regionally, and internationally.

Since the 1950s, international scientific collaborations and the unimpeded movement of germplasm between countries have been key drivers of productivity-enhancing technological change in developing-country agriculture. Many of these international collaborations, germplasm exchanges, and breeding programs have led to significant increases in yield gains for staple crops and improvements in national food security (Evenson and Gollin 2003; Byerlee and Dubin 2008; Renkow and Byerlee 2010). From the revolutionary changes brought about by the introduction of semi-dwarf rice and wheat varieties in South Asia during the 1960s, to the more incremental changes in breeding roots and tubers for abiotic stress resistance and nutritional enhancement in Africa during later decades, germplasm exchanges and international collaboration have sat squarely at the center of these endeavors.

At the center of this changing policy landscape is the Convention on Biological Diversity (CBD), which entered into force in 1993 with the aim of conserving natural capital and rewarding communities for their historic role in conserving and improving genetic resources.

Two subsequent agreements - the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which entered into force in 2004, and the 2014 Nagoya Protocol - advance these aims by establishing guidelines for signatory countries to manage the conservation and exchange of genetic resources and to set terms for sharing the benefits of improvements made with those resources. Since then, many developing and industrialized countries have introduced national laws and regulations to ensure compliance with the spirit of these international treaties. Against this backdrop, many countries are simultaneously introducing plant variety protection laws based on an international standard recommended by the International Union for the Protection of New Varieties of Plants (UPOV). UPOV provides the architecture for national laws and regulations that are consistent with the 1995 Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement that is administered by the World Trade Organization (WTO).

Not surprisingly, national policy reform efforts designed to increase compliance with these various international regimes appear to be producing unintended frictions alongside the intended safeguards to natural biodiversity endowments (in the case of the CBD and Nagoya Protocol), strengthening of the multilateral system for genetic resource conservation and exchange (in the case of the ITPGRFA) and incentivizing crop-sciences industry investment and growth (in the case of UPOV). National regulations developed in compliance with these international treaties are introducing complex and sometimes muddled rules, guidelines, and norms that delineate how genetic resources may be conserved, exchanged, and used. Regulatory systems are becoming more complex with respect to the conditions under which germplasm may be shared with other countries, used for research purposes, or secured under plant variety protection laws.

As a result, some scholars have expressed concerns that these agreements will constrain scientific advancement in the life sciences, whether via reductions in germplasm exchanges imposed by the Nagoya Protocol (Jinnah and Jungcurt 2009), via restrictive intellectual property rights regimes that are compliant with UPOV (De Jonge and Munyi 2017), or through other pathways. Other scholars suggest that the policy impact pathways are far more complicated than originally thought, and thus fraught with considerable case- and country specific unintended consequences (Welch et al. 2013; Spielman and Ma 2016). The ambiguity associated with changing incentives suggests the need for a stronger body of empirical evidence (Naseem, Spielman, and Omamo 2010).

Meanwhile, countries' expectations of the gains from benefit-sharing arrangements, stronger IPR regimes, and stricter seed laws, seem to be growing faster than the actual realization of benefits. These changes may have a long-lasting influence on research priority-setting and collaboration strategies, with potentially non-trivial outcomes for many developing countries where the need for continued investment in genetic improvement of staple foods is needed to increase food and nutritional security.

This paper provides a novel characterization of the changing landscape governing international germplasm exchanges. Emphasis is placed on culling evidence from historical patterns and trends to better understand how national regulatory changes associated with the CBD and ITPGRFA affected the movement of genetic resources to be able to draw lessons for related policy changes such as the Nagoya Protocol.

This paper is structured as follows. Section 2 reviews prior research that attempts to analyze international germplasm movements and the influence of international treaties on these movements. Section 3 provides a description of patterns and trends in international exchanges and a characterization of the challenges associated with these trends. Section 4 digs deeper into the analysis of global network structure of germplasm, comparing the networks and their properties in the four years before and after the entry into force of CBD and the four years before and after the entry into force of ITPGRFA. Section 5 uses econometric analysis exploring the effect of being a party to CBD and/or ITPGRFA after accounting for the effect of overall trends, country-specific fixed effects, and other variables that may also influence germplasm flows using a Panel Latent Class Negative Binomial Model. Section 6 discusses the implications of these changing patterns and trends, and explores economic models to better evaluate their impact.

2 Changing landscapes and patterns in genetic resource exchanges

International exchanges of germplasm in the post-war era have been used with considerable success to address the global food security challenge. One of the earliest examples of germplasm exchanges used to combat a major food security challenge is the international effort to breed wheat rust resistance for a wide range of countries and ecologies (Dubin and Brennan 2010). That collaboration highlights the role played by an open-access system of germplasm exchange supported by a well-funded public-goods research system that, in turn, gave rise to similar programs that underwrote the Green Revolution (Hazell 2010). To be sure, the global enterprise in germplasm exchange has made significant advances in reducing global hunger and malnutrition through genetic improvement of food staple crops.

But to better understand how changing genetic resources policy landscape might affect similar outcomes in the future, it is important to recognize the tensions between international agreements that influence international germplasm flows. International germplasm exchanges became a subject of increasing controversy beginning in the early 1990s. Recalling the colonial origins of resource extraction in the South, many developing countries sought to protect their natural endowments of biodiversity from further exploitation by industrialized countries, multinational firms, and other interests. A popular concern driving this protectionism was the fear of "biopiracy" or the extraction of biological materials by for-profit companies without recognition or remuneration to communities that have conserved these resources for generations (Shiva 1999). While populist in nature, these concerns were not entirely unfounded as stronger IPR regimes evolved rapidly with the introduction of biotechnology applications to agriculture and questions of ownership over genetic resources and constructs (Spielman 2007; Falcon and Fowler 2002; Pingali and Traxler 2002). As shown in Timeline 1 below, the 1960's, 70's, and 80's that enjoyed a relatively free and increased level of germplams transfers between countries were met with a series of negotiations in the last two years of the 1980s and first three years of 1990s, that culminated in the entry into force of the Convention on Biological Diversity in December 1993.

TIMELINE 1: *Chronology of Major International Germplasm Regulatory Changes*

1960s, 70s, & 80's	Decades of relatively free flows of germplasm
1991 & 1992	Negotiation years for CBD
December 29, 1993	CBD enters into force
October 26, 1994	'in-trust' agreement of CGIAR genebanks with FAO
November 3, 2001	ITPGRFA opened for signature
June 29, 2004	ITPGRFA enters into force
October 29, 2010	Nagoya Protocol adopted
October 12, 2014	Nagoya Protocol entered into force

The scope of CBD extends to any material of plant, animal, microbial, or other origin containing functional units of heredity. CBD has a triple objective of conserving genetic diversity, making its use sustainable, and ensuring an equitable sharing of the benefits flows derived from them. The convention provides the property rights of genetic resources to member countries and they have the sole competence to decide under what conditions access to their genetic resource can be granted and resulting benefits shared (Pauchard, 2016).

The change in tenor around international germplasm flows caused by CBD was felt acutely by those charged with facilitating the movement of genetic material for agricultural development purposes. Despite the international genebanks' importance to global breeding efforts, their status faced uncertainty as the CBD came into effect as of 1993. Though the CBD, established a system governing all biodiversity, including ex situ collections of germplasm that most countries formally ratified, it did not specifically address the CGIAR collections, thus leaving their status in doubt (Gotor, Caracciolo, and Watts, 2010). Gotor, Caracciolo, and Watts (2010) note that at that moment in history, "the conflict between the well-established CGIAR practice and internal policy of making germplasm freely available and the emerging international policy framework establishing biodiversity as a sovereign resource raised questions about the legal status of the CGIAR collections." In effect, individual countries had newfound rights to exercise their national sovereignty over their endowments of plant genetic resources by restricting access or even requesting the return of their materials held by CGIAR genebanks. The access and benefit sharing regime under CBD that is based on bilateral contracts between donor and recipient countries was also problematic for the multilateral regime that the CGIAR genebanks operate under.

To resolve this potential conflict, the CGIAR centers negotiated with the Food and Agriculture Organization of the United Nations (FAO) to formally place their genebanks collections under a public trusteeship. On 26 October 1994, FAO signed agreements with each individual CGIAR Center, thus bringing the CGIAR germplasm collections formally under the auspices of FAO and establishing them as being held 'in-trust'. Under the 'in-trust' agreement, genetic materials managed by the CGIAR is made available without restrictions, no intellectual property rights over the germplasm could be sought, and recipients of transferred germplasm and its related information could neither claim ownership nor seek any intellectual property rights over that germplasm or information related to it (Gotor, Caracciolo, and Watts, 2010).

An alternative access and benefit sharing arrangement based on multilateral arrangements as opposed to the bilateral contract under CBD was spearheaded by FAO's commission on Genetic Resources for Food and Agriculture, which led to the entry into force of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA or the Treaty) in November 2004. ITPGRFA applies to 35 food crops and 29 forages (crops under Annex 1 of the treaty) that are deemed to be of extreme importance to global food security.

Countries that are parties to the treaty must grant unrestricted access to these crops. The monetary and non-monetary benefits are shared among all States Parties through a common fund and the corresponding knowledge and information are collected in a common database (Pauchard, 2016). In addition, the new agreements signed between the CGIAR centers and the governing body of the treaty replaced the 'in-trust' agreements to bring the CGIAR collections under the purview of the treaty. Unrestricted access to the crops that fall under Annex 1 of the treaty indicates that ITPGRFA can have the opposite effect on germplasm exchanges from countries that are parties to the treaty as opposed to those that are party only to CBD.

Concerns about the possible free use of genetic resources despite the adoption of the CBD incited State Parties to implement a set of binding rules dealing with ABS elements of the CBD. Years of negotiation on the issue resulted in the adoption of a binding protocol to the convention - the Nagoya Protocol that was adopted in October 2010 and entered into force in October 2014 (Pauchard, 2016). The protocol requires parties to adopt a clear national ABS legislation, establish a competent national authority that can grant access to germplasm requests from recipients through mutually agreed terms. As a strong protocol of the loose convention, germplasm exchanges from parties of the Protocol is expected to slow down at least until the necessary capacity is established with this regard.

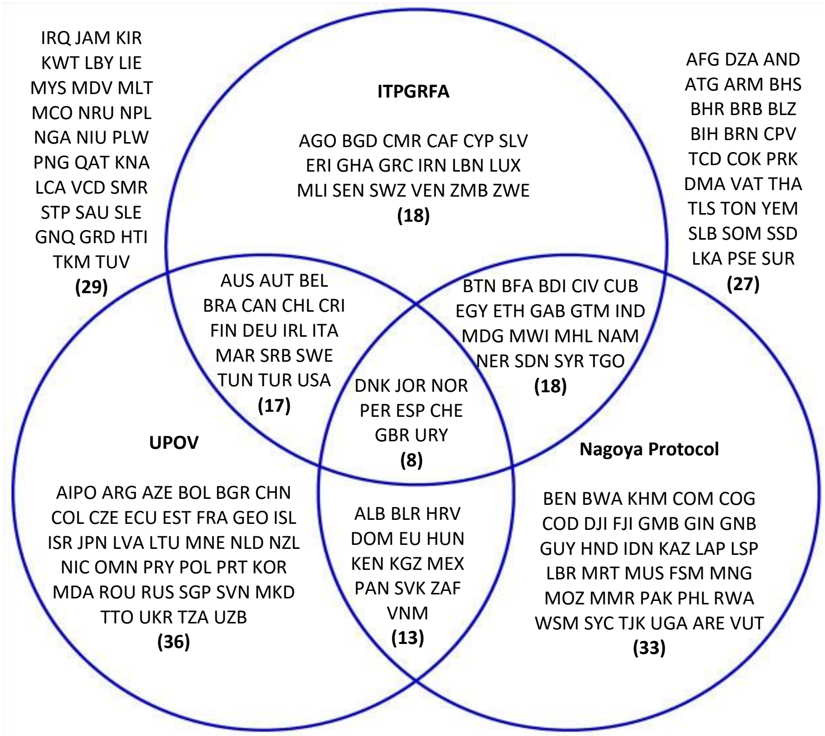
Countries join these different treaties, conventions, and protocols in different years. All 191 countries in this study are parties to CBD with the exception of the Unites States. 88 countries became parties to CBD in 1994, 36 countries in 1995, 35 countries in 1996, and the rest of the countries after 1996. There is more variation in ITPGRFA membership as 144 countries are members of the treaty where as 51 countries are not parties. 57 countries joined the treaty in 2004, 14 countries in 2005, 33 countries in 2007, and the rest in more recent years. As of mid 2017, 101 countries became parties to the Nagoya Protocol. 52 countries became parties to the Protocol in 2014 and 49 countries between 2015 and 2017. Figure 1 illustrates the overlapping membership in the various international agreements mentioned above. The United States joined ITPGRFA in December 2016 and the treaty entered into force in March 2017.

This then brings us to the crux of the issue. How will policy and regulatory changes associated with CBD, Nagoya Protocol, and ITPGRFA affect future genetic resource flows, particularly for developing countries? Clearly, many countries will face significant challenges in navigating this rapidly changing landscape and formulating policies and regulations that balance compliance with multiple agreements against scientific freedom to operate both nationally and globally. Germplasm transfer data becomes avaialbe in two to three years lag, making it difficult to directly analyze the impact of the Nagoya Protocol on germplasm exchanges. Thus, this paper focuses on identifying the impact of CBD and ITPGRFA exploring within country variation in membership of these regulatory regimes across time as well as cross sectional differences of membership across countries in a given period. The next section examines the historical patterns and trends in international germplasm exchanges to better frame the analysis of future social and economic outcomes from this changing policy landscape.

3 Trends and Major Origins for Plant Genetic Materials

The main sources of data for international germplasm transfers for this study comes from GENESYS, a global portal on plant genetic resources for food and agriculture, developed through a collaboration between Bioversity International, Global Crop Diversity Trust, and Secretariat of the ITPGRFA. When established in 2011, GENESYS was a one-stop access point to the information provided by the European Plant Genetic Resources Search Catalogue, the System-wide Information Network for Genetic Resources, and the Genetic Resources Information Network of the United States Department of Agriculture (GENESYS, 2017). Thus, GENESYS reported providing access to about one third of the accessions estimated to be held worldwide. As of mid 2017, GENESYS provides data on more than 3.6

Figure 1: *Membership in international agreements on plant genetic resources*



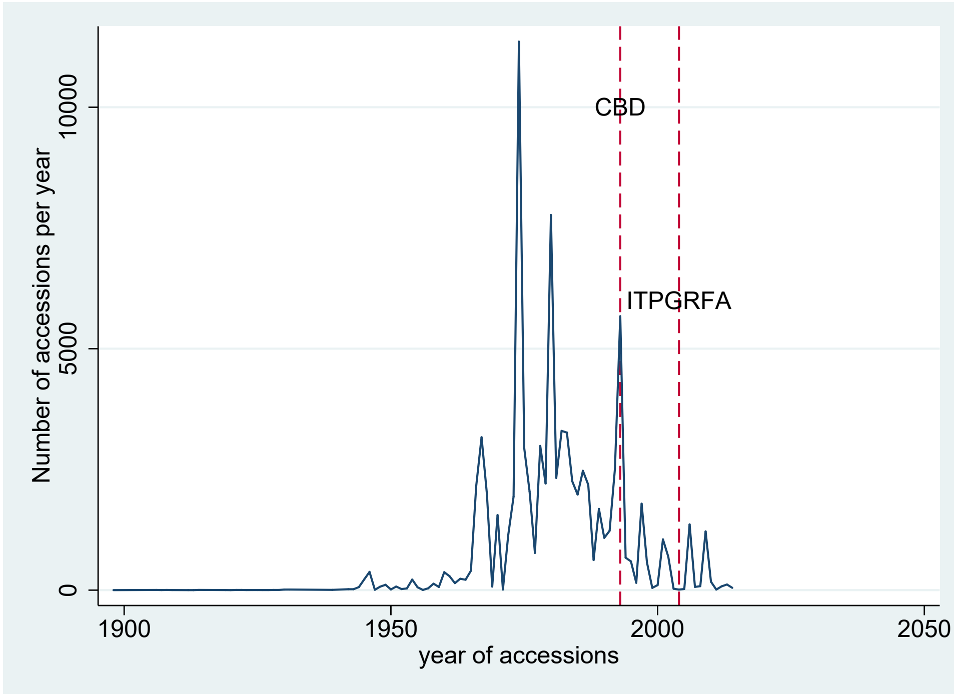
Source: Authors.
Note: [a] key to the three three-letter country codes used in the diagram is available from http://wits.worldbank.org/wits/wits/witshelp/content/codes/country_codes.htm.

million accessions held in 482 institutes worldwide, including CGIAR genebanks, USDA ERS National Plant Germplasm System (NPGS), and EURISCO (a web-based catalogue that provides information about ex situ plant collections maintained in Europe). The analysis in this study focuses on five major crops: sorghum, pearl millet, beans, cow peas, and maize.

3.1 Sorghum

The data on sorghum accessions from GENESYS comes from genebanks in India and USA that account for 47% and 48% of the total sorghum germplasm under GENESYS. India's prominence as a holding country for sorghum germpasm is partly the result of the presence of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the country, as the CGIAR center with mandates on sorghum, millet, chickpea, pigeonpea,

Figure 2: *Overall Trend of sorghum genetic material flows*



and groundnut.

As shown in Figure A.1, Ethiopia is the most important country as a source of sorghum genetic material, followed by Yemen, Sudan, USA, Mali, and India.

Sorghum accessions have seen significant increase in the 1970s and 1980s, with a sharp decline following 1993 (Figure 2). As discussed above, 1993 is the year in which the Convention on Biological Diversity (CBD) came into effect, and 83% of countries became parties to CBD between 1993 and 1996.

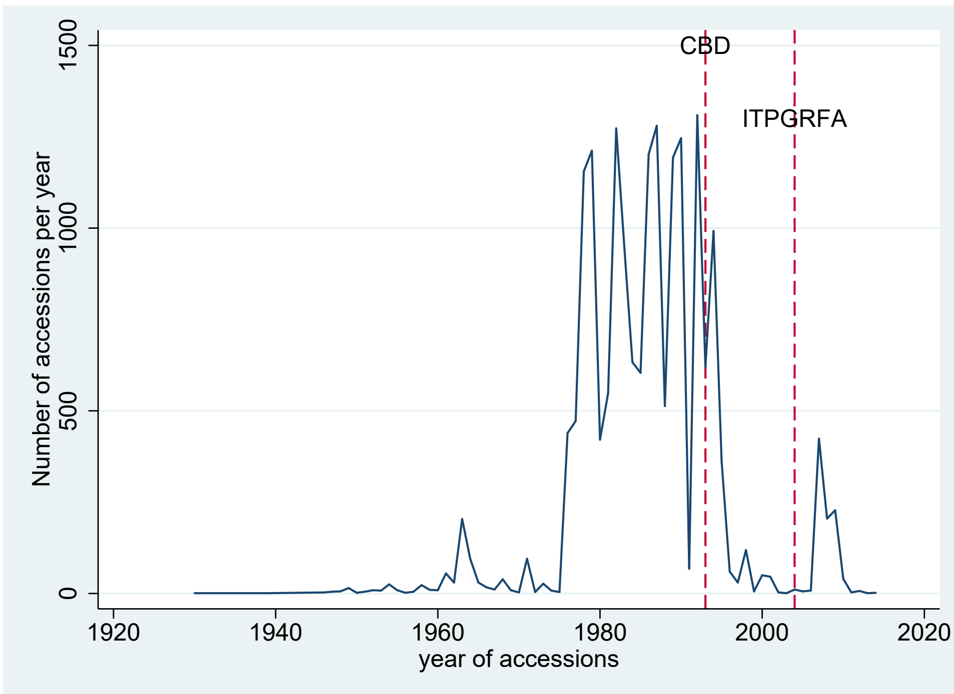
3.2 Pearl Millet

As with sorghum, most of the accessions for pearl millet is located in India. Genebanks in India (mainly ICRISAT) account for 88% of the accessions that GENESYS has information on, and genebanks in the USA hold about 9% of the accessions.

Nigeria, Niger, Zimbabwe, Mali, Namibia, and Sudan are the five most important contributors of germplasm for pearl millet (Figure A.2).

Half of these accessions occur in the 1980s. 20% and 16% of the accessions occur in the 1970s and 1990s (Figure 3). Figure 3 also shows that the major genebanks of the world have seen a sharp decline in the number of accessions after the mid 1990s, as is the case for sorghum. There appears to be a modest increase in pearl millet germplasm flows in the post-2004 ITPGRFA period.

Figure 3: *Overall Trend of Pearl Millet genetic material flows*



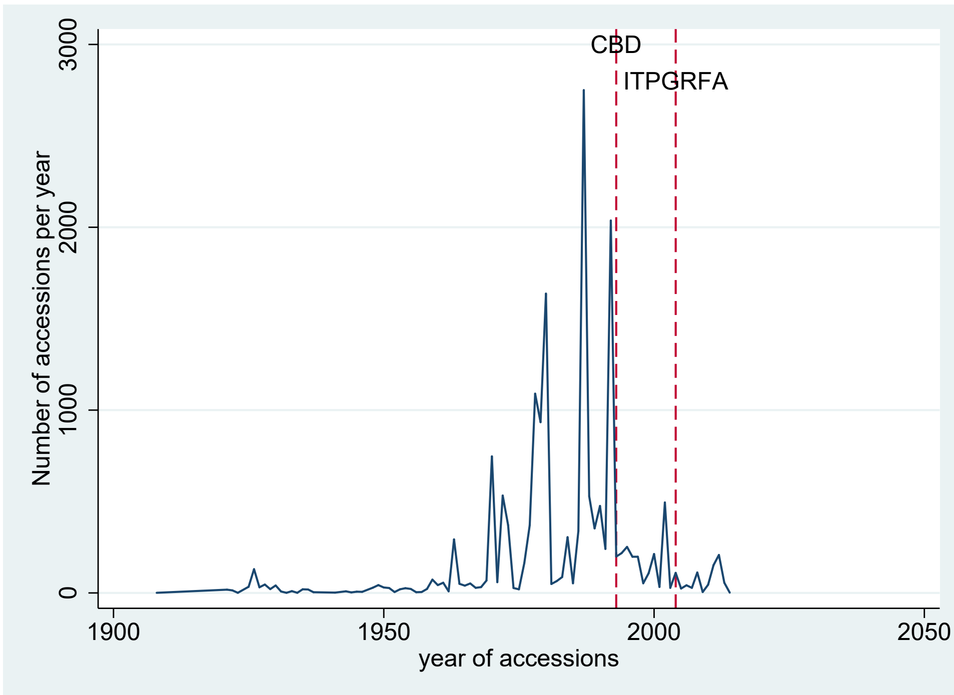
3.3 Cow Peas

Out of the over 18,000 accessions of genetic materials for cow peas under the GENESYS portal, 64% is held in Nigeria, 20% in the USA, 7% in Taiwan, and 4% in Australia. The International Institute of Tropical Agriculture (IITA) of the CGIAR, with a focus on cow peas, cassava, and other crops, is located in Nigeria.

Togo, Niger, Botswana, Nigeria, and USA are the main origins of genetic materials for cow peas (Figure A.4).

One-third of the accessions were acquired in the 1970s, another one-third in the 1980s, and one-fourth the 1990s. Accession of genetic materials has significantly slowed down beginning early 1990s (Figure 4).

Figure 4: *Overall Trend of Cowpeas genetic material flows*



3.4 Maize

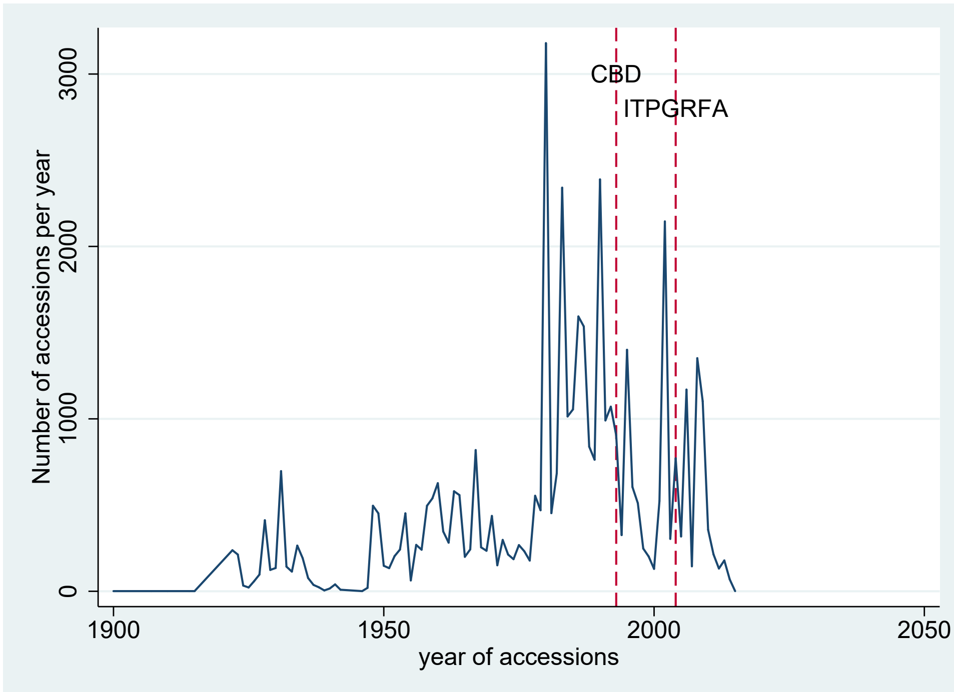
Mexico and USA each hold 28% of the genetic materials out of the more than 51,000 accessions of maize reported under GENESYS. Russia follows third with a holding of 23% of the accession. Other major holders of maize accessions include Italy, Yugoslavia, Australia, Slovakia, Bulgaria, and Nigeria.

USA is the most important country as the origin of genetic materials for maize (Figure A.5). The rest of the top ten position in terms of importance as a source of genetic materials for maize is held by Latin American countries - Mexico, Brazil, Peru, Colombia, Argentina, Chile, Bolivia, Guatemala, and Uruguay (Figure A.5).

Significant number of accessions for maize genetic materials dates back to the 1920s. Number of accessions got momentum in the 1980s and 1990s, which account for 42% and

15% of the 29,000 accessions that GENESYS has information on (Figure 5). Like the other crops discussed above, accessions of maize germplasms showed a sharp decline beginning the early 1990s (Figure 5).

Figure 5: *Overall Trend of Maize genetic material flows*



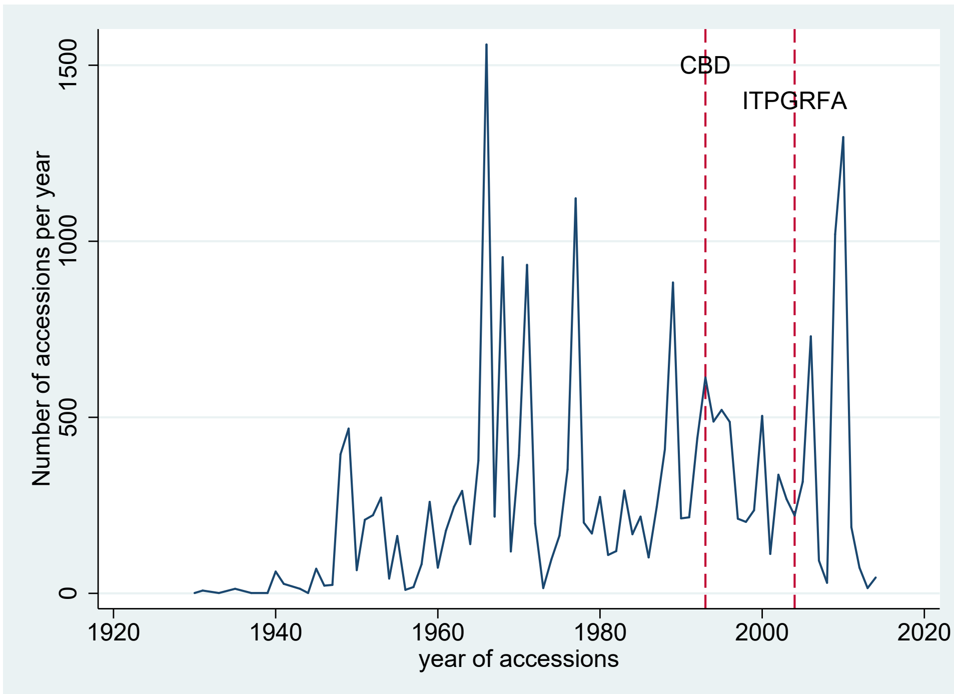
3.5 Beans

Of the 47,000 accessions of beans genetic materials reported under GENESYS, 68% is held in Colombia, the headquarters of the International Center for Tropical Agriculture (CIAT) which is the lead CGIAR center working on beans and cassava. Genebanks in the USA held about 28% of beans accessions under GENESYS.

Latin America is the bio-diversity hub for beans. As such, Mexico, Peru, Guatemala, and Brazil are the four most important contributors of genetic materials for beans, followed by Turkey, USA, Ecuador, and Honduras. See Figure A.3 for further details.

Accessions of genetic materials for beans has a long history, with significant number of accessions dating back to the 1950s and 1960s (Figure A.3). The 1990s and 2000s, however, have seen significant reductions in the number of genetic materials acquired by these genebanks, with the exception of 2009 and 2010 where there has been a spike in the number of accessions, mainly driven by genebanks in the United States.

Figure 6: *Overall Trend of Beans genetic material flows*



4 Changes in Network Structures for International Germplasm Transfers

The preceding section shows that there is a general downward trend in the number of accessions acquired by the major gene banks in the world. There is also a sharp decline around 1993 for almost all of the five crops under consideration in this study - sorghum, pearl millet, beans, cow peas, and maize. See Figures 2, 3, 6, 4, and 5.

Thus, in this section we advance the discussion in two ways. First, we focus our attention on two major regulatory shocks in the international germplasm transfers - the coming into effect of the Convention on Biological Diversity (CBD) in 1993 and that of ITPGRFA in

2004. Taking the lesson from the preceding section, we will only compare relatively short periods (four years) around the CBD and ITPGRFA so that we do not conflate potential changes as a result of the regulatory shock from general trends.

Though the CBD gets into force in December 1993, countries became parties to CBD staggered between 1993 and 1996, the four-year period in which 83% of the countries became parties to CBD. Accordingly, we compare germplasm exchanges in the four year period prior to the first entry into to force of CBD (1990-1993), with the four year period after CBD (1994-1997). Similarly, we compare germplasm flows in the four years before and after the entry into force of ITPGRFA in 2004 to analyze the effect of the treaty on global germplasm exchanges.

Second, rather than looking at trends in overall volume of transfers, we analyze how the network structure for international germplasm changes before and after the CBD and ITPGRFA. In addition to graphical depiction, the network structure is analyzed using degree centrality - the number of ties (or germplasm transfer relationships) a country has, and how it changes over time. Both indegree centrality (the number of countries that provide germplasm to a country in focus) and outdegree centrality (the number of countries the country in focus provides germplasm to) are used in the analysis. However, given the fact that our data comes from selected gene banks participating in GENESYS (and the country they are located at), we have a better picture of changes in the number of countries providing germplasm to these gene banks rather than the number of countries the gene banks give their germplasm to. As such, the indegree centrality measure provide a better picture of the network structure and its changes over time.

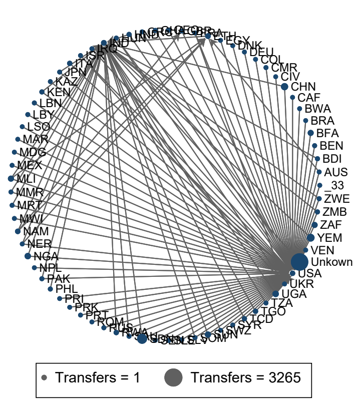
4.1 Sorghum

Figures 7a and 7b show that the network structure of sorghum germplasm exchanges has become less dense and the network size has decreased in the four years before CBD and the four years after CBD, with average indegree centrality decreasing from 0.97 to 0.56. Figures

7c and 7d show that the network structure has passed through a similar change in network size in the four years before and after ITPGRFA with indegree centrality falling from 0.81 to 0.46. Though one would expect a different pattern in network size changes due to CBD and ITPGRFA, this is not clear from the network maps in Figure 7.

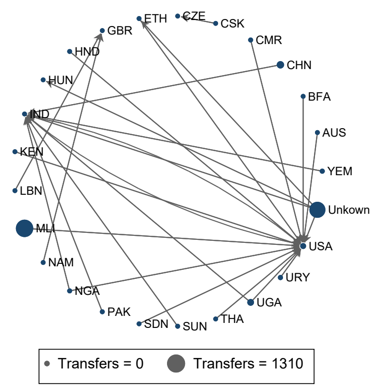
Figure 7: *Network structure of genetic materials distribution for sorghum*

(a) *1990-1993, the four year period before CBD*



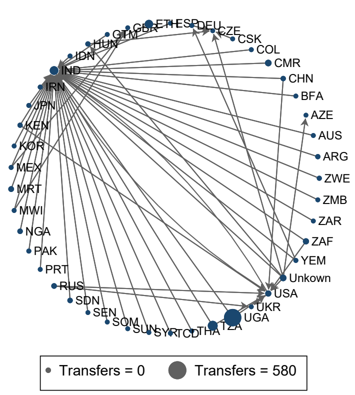
Indegree centralization= 0.965

(b) *1994-1997, the period most countries became parties to CBD*



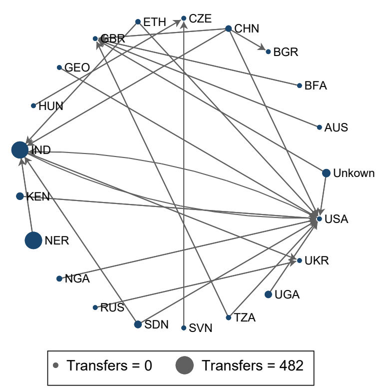
Indegree centralization= 0.561

(c) *2001-2004, the four years before ITPGRFA*



Indegree centralization= 0.808

(d) *2005-2008, the four years after ITPGRFA*



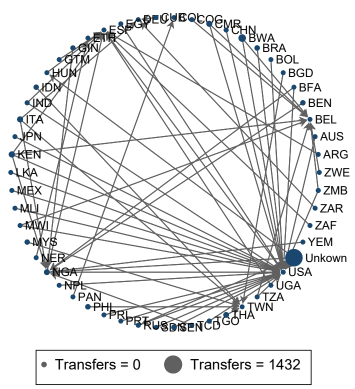
Indegree centralization= 0.463

4.2 Cow Peas

The network structure for international germplasm transfer of cow peas show similar dynamics. The networks get less dense in the subsequent four years before and after the

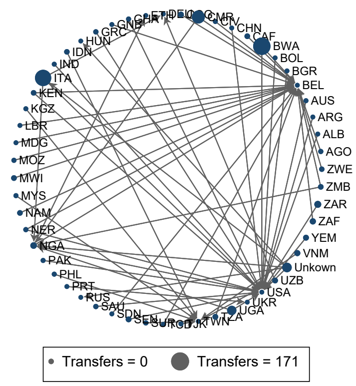
Figure 8: *Network structure of genetic materials distribution for Cow Peas*

(a) *1990-1993, the four year period before CBD*



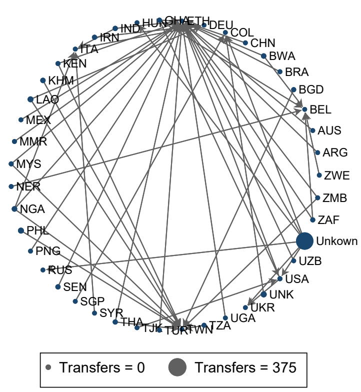
Indegree centralization= 0.477

(b) *1994-1997, the four years after CBD*



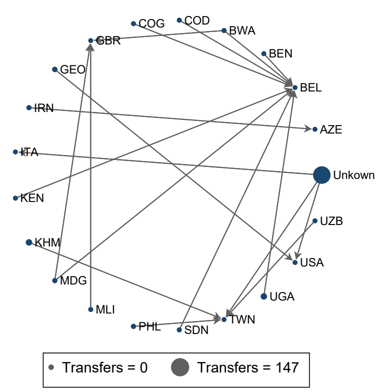
Indegree centralization= 0.375

(c) *2001-2004, the four years before ITPGRFA*



Indegree centralization= 0.506

(d) *2005-2008, the four years after ITPGRFA*



Indegree centralization= 0.373

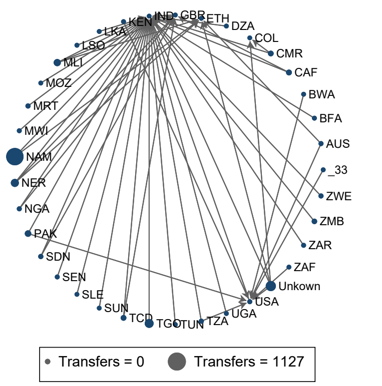
coming into force of CBD (Figures 8a and 8b). The average number of ties has decreased from 0.48 in the four years before CBD to 0.38 after CBD. Similarly, Figures 8c and 8d show that the network size has decreased in the four years before and after ITPGRFA. The indegree centrality decreased from 0.51 to 0.37 between the two periods around ITPGRFA.

4.3 Pearl Millet

The network structure for international germplasm transfers for pearl millet remains stable in the four years before and after CBD, with an indegree centrality of about 0.8

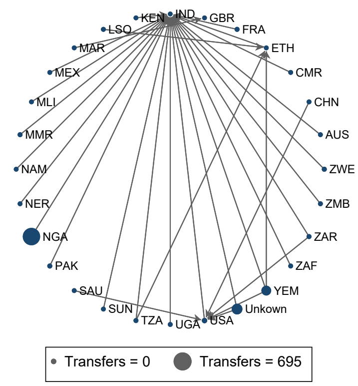
Figure 9: *Network structure of genetic materials distribution for Pearl Millet*

(a) *1990-1993, the four year period before CBD*



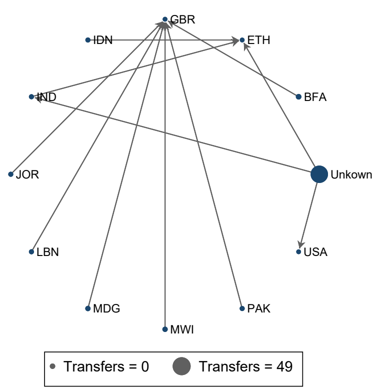
Indegree centralization= 0.789

(b) *1994-1997, the four years after CBD*



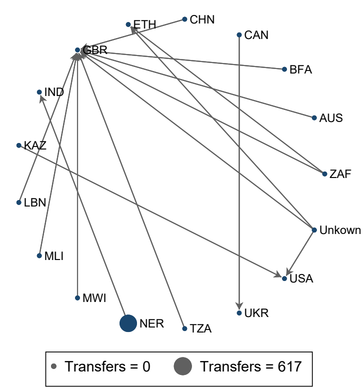
Indegree centralization= 0.802

(c) *2001-2004, the four years before ITPGRFA*



Indegree centralization= 0.504

(d) *2005-2008, the four years after ITPGRFA*



Indegree centralization= 0.539

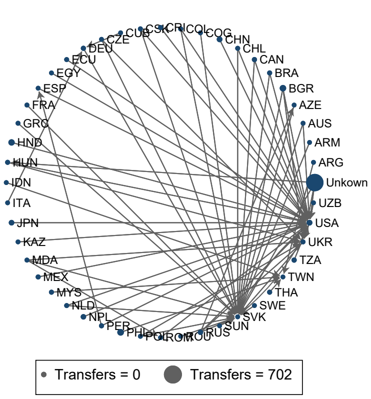
(Figures 9a and 9b). Similarly, the network size remained stable in the four years before and after ITPGRFA, with an indegree centrality of about 0.5 (Figures 9c and 9d).

4.4 Beans

The network size for international germplasm transfers of beans has decreased in the four years before and after the entry into force of CBD (Figures 10a and 10b). The indegree centrality decreased from 0.53 to 0.40 between the two periods. However, the network remained stable in the four years before and after ITPGRFA with slight increase in network

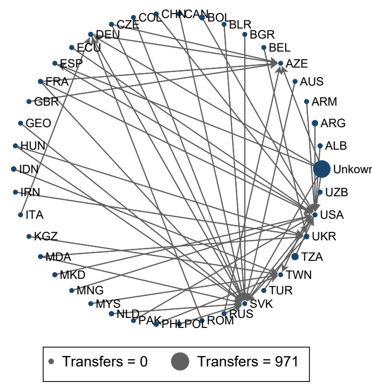
Figure 10: *Network structure of genetic materials distribution for Beans*

(a) *1990-1993, the four year period before CBD*



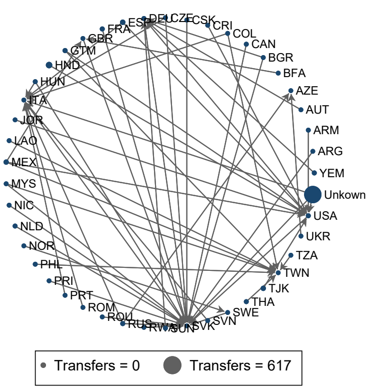
Indegree centralization= 0.534

(b) *1994-1997, the four years after CBD*



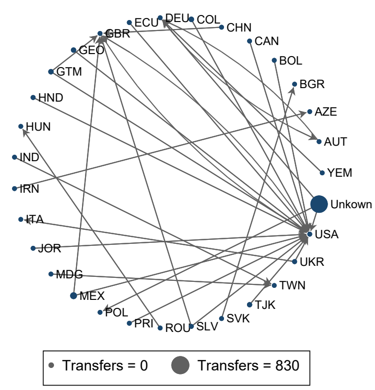
Indegree centralization= 0.395

(c) *2001-2004, the four years before ITPGRFA*



Indegree centralization= 0.436

(d) *2005-2008, the four years after ITPGRFA*



Indegree centralization= 0.482

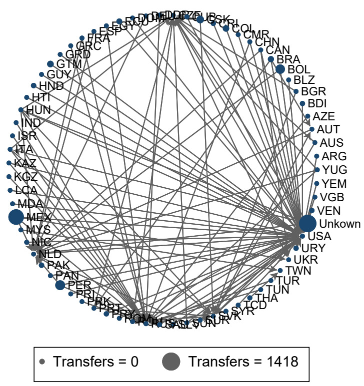
size in the post-ITPGRFA period (Figures 10c and 10d), an expected pattern given the different incentive structures of the convention and the treaty on countries' willingness to participate in international germplasm exchanges.

4.5 Maize

The network structure for maize germplasm transfers involve many countries compared to the rest of the crops under this study. The network structure has gotten less dense in the consecutive four years before and after CBD (Figures 11a and 11b) as well as in the four

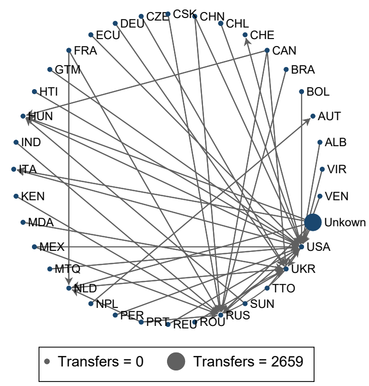
Figure 11: *Network structure of genetic materials distribution for Maize*

(a) *1990-1993, the four year period before CBD*



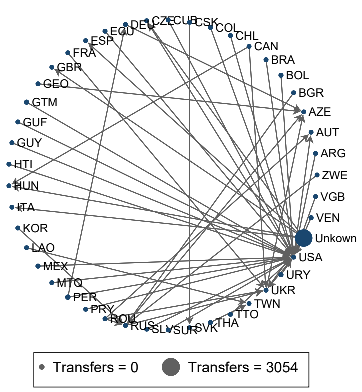
Indegree centralization= 0.558

(b) *1994-1997, the four years after CBD*



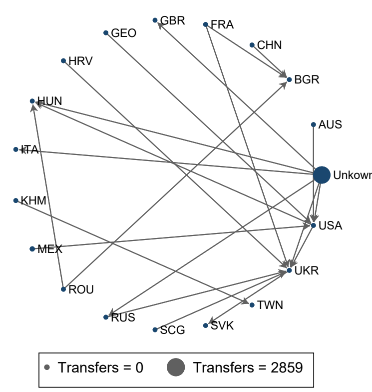
Indegree centralization= 0.403

(c) *2001-2004, the four years before ITPGRFA*



Indegree centralization= 0.486

(d) *2005-2008, the four years after ITPGRFA*



Indegree centralization= 0.287

year periods before and after the entry into force of ITPGRFA (Figures 11c and 11d).

Overall, the network analyses in this section show mixed results in the direction of changes associated with the CBD and ITPGRFA. As expected, the entry into force of CBD is associated with reductions in network sizes in sorghum, cow peas, beans, and maize, with the exception of pearl millet that exhibit a stable network in the two periods. On the other hand, the entry into force of ITPGRFA has the expected positive association with levels of germplasm flows only for beans and pearl millet. For sorghum, cow peas, and maize, the network density of germplasm transfers has fallen between the fours before and after ITPGRFA. These mixed results make it difficult to discern a clear descriptive association between the changes in the regulatory regimes in the form of CBD and ITPGRFA and international germplasm flows.

However, creating causal linkages between such international policy changes and global germplasm flows require further exploration beyond the trend and network analyses. The analysis of the impact of CBD and ITPGRFA over time is problematic because germplasm flows can reduce over time due to factors that are distinct from regulatory changes. These factors include improvements in the availability of characterization and evaluation data that allows researchers to make more specific and targeted requests for materials; improvements in the availability and accessibility of germplasm held in national genebanks; changes in funding for public breeding; membership in competing regulatory regimes; and other time and country specific confounders. The next section deals with these issues using an econometric approach.

5 Econometric Analysis

The econometric analysis in this section explores the role of CBD and ITPGRFA on germplasm flows and disruptions by netting out the effect of overall trends and other confounding factors. We used the chronology of international regulatory changes to classify the study period into Pre-CBD decade (1984-1993), CBD decade (1994-2003), and ITPGRFA and CBD decade (2004-2014). During the CBD-decade, there are countries who are parties to the convention and those that are not. During the ITPGRFA decade, there are countries that are parties to CBD only, or those that are parties to both CBD and ITPGRFA. [1] The effect of CBD is identified by comparing the effect of being a party to CBD as compared to not being a party to CBD, on the flow of germplasm coming out of a country during the CBD decade (1994-2003). The effect of overall declining germplasm exchanges is accounted

[1]The data shows that there is no country that is party to ITPGRFA but not CBD. There is one country, USA, that is not party either to CBD or ITPGRFA, thus excluded from the analysis as we will not be able to separate out country fixed effects from the regulatory regime the country is in.

for since countries are being compared within the same time period. Similarly, the effect of ITPGRFA is identified by comparing the effect of being parties to both CBD and ITPGRFA, with that of being parties only to CBD during the ITPGRFA and CBD decade (2004-2014) on germplams flows coming out of a country in that period. In both cases, we control for other confounding factors such as land area cultivated by the crop - as a proxy measure of the suitability of the country as a source of genetic origin for the crop, and other observed and unobserved time-invariant characteristics of a country that can influence the country's engagement with the world in germplasm flows.

5.1 Empirical Model

The empirical model for the econometric analysis to understand the effect of policy and regulatory changes on the global flow of germplasm, is informed by (i) the fact that the germplasm transfer variable is a count data, (ii) the presence of different groups of countries in terms of germplasm exchanges - some countries serving as the frequent sources of origin for germplasms, some as less frequent sources of origin, and some with zero transfers in the three decades under study, (iii) the presence of dispersion in the count measure of germplasm transfers and (iv) the influence of unobserved country-level heterogeneity that is fixed over time and yet can potentially influence germplasm transfers from the country.

The empirical analysis employs a Panel Latent Class Negative Binomial Model as appropriate to analyze the data. The Negative Binomial distribution is chosen as it can represent count variables with dispersion as is the case in our data set, where the dispersion parameter can be estimated within the model. The latent class (or finite mixture) formulation provides a natural classification of countries as each class can be seen as a 'type' of countries in the network of germplasm exchanges for a given crop, while the panel nature of the data allows individual hetrogeniety within a class.

The basic panel data negative binomial model for a count number of germplasm transfers

y from country i at time t is assumed to follow a Negative Binomial distribution as follows:

$$Prob(Y = y_{it}|\mathbf{x}_{it}, \epsilon_i) = \frac{\Gamma(\tau + y_{it})}{\Gamma(y_{it} + 1)\Gamma(\tau)} \mu_{it}^{\tau} (1 - \mu_{it})^{y_{it}} \tag{1}$$

$$\mu_{it} = \tau/(\tau + \lambda_{it}); \lambda_{it} = exp(\beta' \mathbf{x}_{it} + \epsilon_i)$$

$\forall y_{it} = 0, 1, 2...;$, where $\mathbf{x}_{it}$ refers to variables that can influence germplasm flows such as being a party to international treaties such as CBD, ITPGRFA, and their interactions, the amount of land under cultivation for the crop under consideration, presence of ABS regulations, total arable land in the country, and country specific unobserved random effects. τ is a constant over dispersion parameter to be estimated and Γ refers to the Gamma distribution.

In latent class models (LCM) the set of countries are assumed to be divided into J distinct classes with class proportions $\pi_1, ..., \pi_J$, where $\sum_{j=1}^{J} \pi_j = 1$, and $0 \leq \pi_j \leq 1$. The coefficients will be different for each class of countries and has to be estimated with the class, $j = 1, ...J$, to which a country belongs to. The panel LCM model is, thus, given as

$$Prob(Y = y_{itj}|\mathbf{x}_{it}, \epsilon_{ij}) = \frac{\Gamma(\tau_j + y_{itj})}{\Gamma(y_{itj} + 1)\Gamma(\tau_j)} \mu_{itj}^{\tau_j} (1 - \mu_{itj})^{y_{itj}} \tag{2}$$

$$\mu_{itj} = \tau_j/(\tau_j + \lambda_{itj}); \lambda_{itj} = exp(\beta_j' \mathbf{x}_{it} + \epsilon_{ij})$$

We parametrize the class probabilities of countries into different classes using a multinomial logit specification where the probability of country i to belong in class j, π_j, as a function of time-invariant country-specific variables, Z_{ij}, as follows:

$$\pi_{ij} = \frac{exp(\theta_j' Z_i)}{\sum_{m=1}^{J} exp(\theta_m' Z_i)}, \quad \theta_J = 1, \quad \sum_{j=1}^{J} \pi_j = 1 \tag{3}$$

The main class-splitting variables, Z_i, in our estimation are region dummies (since sources of biological origin countries usually concentrate in a given region) and average size of land under cultivation by the crop over the time period under consideration as a proxy measure of the suitability of the country as a source of genetic origin for the crop.

We have analyzed more than 195,504 accessions in major gene banks of the world using data from GENESYS, a global portal about Plant Genetic Resources for Food and Agriculture (PGRFA), which is the result of collaboration between Bioversity International, Global Crop Diversity Trust, and Secretariat of the International Treaty on the Plant Genetic Resources for Food and Agriculture. The data in GENESYS represents about a third of the total estimated number of accessions worldwide. The data is analyzed for five crops - sorghum, pearl millet, beans, cow peas, and maize - to be able to discern common trends and changes in network structures in international germplasm transfers across countries. Data on land under cultivation for the different crops is drawn from FAOSTAT. Data on dates countries became parties to international conventions such as the convention on Biological Diversity, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and the Nagoya Protocol is obtained from the Convention on Biological Diversity website.

5.2 Results

The econometric results presented in Tables 1, 2, 3, 4, and 5 show that the effect of being a party to CBD and ITPGRFA on international germplasm transfers differ by crop and by country. The tables present pairwise comparisons of linear predictions of country and time specific regulatory regimes based on estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of each crop. The full set of estimated parameters for each crop are presented in the Appendix (Tables A.1, A.2, A.3, A.4, and A.5).

In the case of cow peas, the latent class estimation assigned 33 countries to class 1 (including important origin countries such as Niger, Botswana, and Nigeria) and 135 countries to class 2 (including Togo - the leading source of cow peas germplasm). There were an average of 3.9 accessions per year from countries in class 1 and an average of 0.9 accessions per year from countries in class 2. Table 1 shows that, during the 2004-2014 period where countries can be parties to either the CBD or ITPGRFA, countries in class 1 who are parties to CBD but not the ITPGRFA exchanged less number of germplasm as compared to countries within the same class that also became parties to ITPGRFA. For countries in class 2, Table 1 shows that during the CBD period (1993 to 2004), countries who were not parties to CBD share more germplasms of cow peas as compared to countries who became parties to CBD. These two sets of results are coherent with expectations since the CBD, in the absence of a working access and benefit sharing mechanism put in place, can make origin countries more conservative to share their germplasm while ITPGRFA, works in the opposite direction as parties must grant unrestricted access to the 35 food crops and 29 forages that are deemed to be extremely important for global food security including the five crops under this study.

Table 1: *Pairwise comparisons of linear predictions of country and time specific regulatory regimes from estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of cow peas*

			Class splitting equation?			
			No		Yes	
	Period	Regulatory Regime in the country	Coef.	SE	Coef.	SE
Class 1	CBD	(Not party to CBD) Vs (Party to CBD)	0.922	0.607	0.969	0.607
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	-.818*	0.422	-.772*	0.428
Class 2	CBD	(Not party to CBD) Vs (Party to CBD)	1.544*	0.869	1.455*	0.866
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	2.664	2.416	-5.511	5.789

CBD period refers to 1993-2003 and ITPGRFA period refers to 2004-2014.
***, **, * shows significance at 1%, 5%, 10% levels.

In the case of sorghum, the Panel LCM model groups 162 countries into class 1 and 24 countries into class 2, where class 2 includes the most important origin countries in sorghum germplasm such as Ethiopia and Sudan. There were an average of 0.6 accessions per year from countries in class 1 and an average of 28 accessions per year from countries in class 2. Table 2 shows that among the most important origin countries in class 2, those that became parties to ITPGRFA share more genetic materials per year compared to those that were parties to the CBD but not ITPGRFA. Thus, the international treaty has the expected impact in terms of improving germplasm transfers for the important food crops such as sorghum from countries that matter most as source of germplasm origin for the crop.

Table 2: *Pairwise comparisons of linear predictions of country and time specific regulatory regimes from estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of sorghum*

			Class splitting equation?			
			No		Yes	
	Period	Regulatory Regime in the country	Coef.	SE	Coef.	SE
Class 1	CBD	(Not party to CBD) Vs (Party to CBD)			-1.394	0.860
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)			-1.192	1.225
Class 2	CBD	(Not party to CBD) Vs (Party to CBD)			-1.020	0.697
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)			-1.389**	0.608

CBD period refers to 1993-2003 and CBD/IT period refers to 2004-2014.
***, **, * shows significance at 1%, 5%, 10% levels.
The model with out class splitting equation fails to converge.

The LCM estimation for pearl millet groups 151 countries into class 1 including the two leading sources of millet germplasm - Nigeria and Niger - and 29 countries into class 2 - including important germplasm origin countries such as Mali, Namibia, and Sudan. Countries in class 1 share an average of 0.57 accessions per year while countries in class 2 share an average of 7.8 accessions per year. The results in Table 3 show that countries in class 2 that are parties to CBD share less than countries in the same class that are not parties to CBD during the 1993-2004 period. Out of the 198 countries that are parties to CBD, only 39 of them have access and benefits sharing (ABS) laws and procedures in place, and more than 90% of these occur after 2004 (CBD, 2017). It is possible that countries that are parties to CBD, particularly in the absence of the expected ABS regulations and offices are likely to be protective of their genetic resources and less likely to have an open door policy until they establish commensurate regulations and offices on ABS.

In the case of maize, the panel LCM model with multinomial logit splitting equation fails to converge and the results are based on the model that does not include such variables. The model groups 147 countries into class 1 and 40 countries into class 2. Countries in class 1 share an average of 0.24 accessions per year while countries in class 2 share an average of 8.7 accessions per year. Countries in class 2 include the top ten sources of maize germplasm outside the US - Mexico, Brazil, Argentina, Peru, Colombia, Chile, Bolivia, Guatemala, and

Table 3: *Pairwise comparisons of linear predictions of country and time specific regulatory regimes from estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of pearl millet*

			Class splitting equation?			
			No		Yes	
	Period	Regulatory Regime in the country	Coef.	SE	Coef.	SE
Class 1	CBD	(Not party to CBD) Vs (Party to CBD)			-2.538	5.060
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)			-6.263	5.220
Class 2	CBD	(Not party to CBD) Vs (Party to CBD)			3.171***	0.650
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)			0.692	0.886

CBD period refers to 1993-2003 and CBD/IT period refers to 2004-2014.
***, **, * shows significance at 1%, 5%, 10% levels.
The model with out class splitting equation fails to converge.

Uruguay. The results in Table 4 show that for countries in class 1 that are less engaged in maize germplasm exchanges, neither CBD nor ITPGRFA makes statistical difference in the amount of germplasm coming out of these countries. For the important maize germplasm origin countries grouped in class 2, Table 4 shows that ITPGRFA has the expected impact on global germplasm exchange as countries that are members of the treaty exchange more germplasm than countries in the same class that are parties only to CBD. However, being parties to CBD has the unexpected impact during the CBD period of 1993 to 2004 as those that became parties to CBD share less than those that are not parties to CBD.

The unexpected result of CBD on maize germplasm exchanges could partly be due to differences in the timing of when the big players in Latin America joined CBD. All of the important maize germplasm origin countries became parties to CBD either in 1994 or 1995, and hence the result in class 2 is coming mainly from comparing countries who joined in 1994 and those in 1995. The top three non-US origin countries for maize - Mexico, Brazil, and Peru - along with other countries in the top ten origins for the crop such as Chile, Ecuador, and Uruguay joined CBD in 1994. If these big players who joined in 1994 continue sharing maize germplasm, then comparing them with the small players in the class that mostly join in 1995 may appear in the econometric estimation as countries that are parties to CBD sharing more than those that are not parties to CBD.

Table 4: *Pairwise comparisons of linear predictions of country and time specific regulatory regimes from estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of Maize*

			Class splitting equation?			
			No		Yes	
	Period	Regulatory Regime in the country	Coef.	SE	Coef.	SE
Class 1	CBD	(Not party to CBD) Vs (Party to CBD)	-0.577	1.006		
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	0.881	1.006		
Class 2	CBD	(Not party to CBD) Vs (Party to CBD)	-1.732***	0.353		
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	-3.187***	0.297		

CBD period refers to 1993-2003 and CBD/IT period refers to 2004-2014.
***, **, * shows significance at 1%, 5%, 10% levels.
The model with class splitting equation fails to converge.

The Panel LCM model for beans groups 47 countries into class 1 and 127 countries into class 2. Countries in class 1 exchange an average of 3.6 accessions per year while countries in class 2 exchange about 0.12 accessions per year. Class 1 countries include the most important origin countries for beans such as Mexico, Peru, Guatemala, Brazil, Ecuador, and Honduras. Table 5 shows that, countries in class 1 that are parties to CBD but not to ITPGRFA share more than countries that are parties to ITPGRFA as well, a result unexpected as the case with maize in a class that is dominated by similar set of countries from Latin America. The unexpected result on ITPGRFA on genetic transfer in beans could partly be because Mexico with its over sized share as an origin country for bean germplasms, as well as other important countries such as Argentina, Bolivia, and Chile are not parties to ITPGRFA and could be deriving the result that countries that are not parties to ITPGRFA share more than those that are parties to the treaty.

Table 5: *Pairwise comparisons of linear predictions of country and time specific regulatory regimes from estimates of Panel Latent Class Negative Binomial Model for global germplasm exchanges of beans*

			Class splitting equation?			
			No		Yes	
	Period	Regulatory Regime in the country	Coef.	SE	Coef.	SE
Class 1	CBD	(Not party to CBD) Vs (Party to CBD)	-0.738	0.905	0.840	0.576
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	0.201	0.687	1.013***	0.370
Class 2	CBD	(Not party to CBD) Vs (Party to CBD)	0.917	0.604	-0.297	0.918
	ITPGRFA (IT)	(CBD but not IT) Vs (Both CBD & IT)	0.591	0.368	0.339	0.733

CBD period refers to 1993-2003 and CBD/IT period refers to 2004-2014.
***, **, * shows significance at 1%, 5%, 10% levels.

6 Discussions and Conclusions

6.1 Implications of the analysis of patterns and trends in international germplasm exchanges

The analysis in this study has a number of implications for the analysis of patterns and trends in international germplasm exchanges. First, and perhaps not surprisingly, it shows that descriptive analysis of trends and network maps of global germplasm flows, though informative in identifying correlations, should be carefully interpreted and need to be supplemented by rigorous analytical models.

Second, the effect of a policy and regulatory shock, such as CBD and ITPGRFA, on global germplasm flows differs on a crop by crop basis as well as on the level of engagement of countries in global germplasm exchange for a crop. For cowpeas, sorghum, and pearl millet, we found that during the 1993-2004 period, among a group of similar countries that are already engaged in meaningful global interactions in germplasm exchanges, those countries that are parties to CBD share less number of germplasms compared to those that are not parties to CBD. In the 2004 to 2014 period where most countries are either parties to CBD or to both CBD and ITPGRFA, we find that for cow peas, sorghum, and maize, countries that are parties to only CBD but not the ITPGRFA share less number of germplasms compared to countries that are parties to ITPGRFA as well.

Third, which is a corollary of the point made above, is that well-intended international regulations meant to facilitate sustainable and equitable use of biodiversity can have unintended consequences. The results indicate that countries that are parties to CBD, particularly in the absence of the expected ABS regulations and offices, are likely to be protective of their genetic resources and less likely to have an open door policy until they establish commensurate regulations and offices on ABS.

Fourth, the positive impact of being a party to ITPGRFA on international germplasm flows, compared to those that are parties only to CBD indicates that the effect of CBD is having a different trajectory before and after the introduction of ITPGRFA. This begs for more future research on the interaction of these different regulatory changes and shocks on global germplasm flows. What happens to germplasm exchanges when more countries are now having strict ABS mechanism under the Nagoya Protocol, as compared to its deliberately loose parent convention - the CBD? What happens to the landscape of the global germplasm exchange as a result of the entry into force of ITPGRFA in the US - by far the biggest player in germplasm exchange of a number of crops and forages - as of March 2017 following its ratification in August 2016? These are topics the authors are currently pursuing and hope to shed light on as data becomes available following these shocks.

Fifth, these international agreements and corresponding national regulations create a policy environment that some times is difficult to navigate for scientists and research institutions. A recent survey response from 209 scientists of Feed the Future Innovation Labs who use genetic resources for food and agriculture (GRFA) in their research shows that scientists spend more time now compared to five years ago on administrative activities related to regulations and permits for GRFA (46%), genetic materials became more protected by ownership rights that carries with it a concomitant rise in restrictions and conditions associated with the material such as restrictions on transfers to third parties (64%) and on commercial or profit use (65%), increased time required to obtain genetic materials in a way that affected the research process (62%), changed their collaboration structures and locations they work in (40%), and ended a research collaboration in the previous two years because of their inability to access genetic resources for food and agriculture (25% of US researchers and 11% of non-US researchers) (Welch et al. 2017). In the face of the changing policy and regulatory landscape and costly coping mechanisms of the R&D community, we believe more research is needed in this area to be able to understand the full costs and benefits of these regulations.

6.2 Final comments on policy implications of changing patterns and trends in international germplasm exchanges

What are some of the scenarios for global scientific collaboration going forward? Scientists may choose to limit the scope of their collaboration to only those colleagues who can effectively deal with regulatory requirements. Scientists may slow their research down as they wait patiently for germplasm requests to wind their way through layers of complex regulatory requirements and uncertainty around approval of their requests. Scientists in some countries may become open, active super-providers of germplasm while others check out completely. Or, at the extreme, scientists may simply abandon entire lines of research and focus their minds elsewhere. The implications in terms of both time and cost for crop improvement and global food security are potentially significant.

Now more than ever, changes in the global policy regimes and in national-level ground realities are testing the global research system's capacity to advance collaborative science. The decisions that scientists take today will likely affect the nature of tomorrow's solutions to the world's food security challenges. And without a better sense of the intended and unintended consequences of changes in genetic resources policy, uncertainty may significantly undermine the collaborative bedrock of global agricultural science.

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A Appendix

Figure A.1: *Major origins for sorghum genetic material flows*

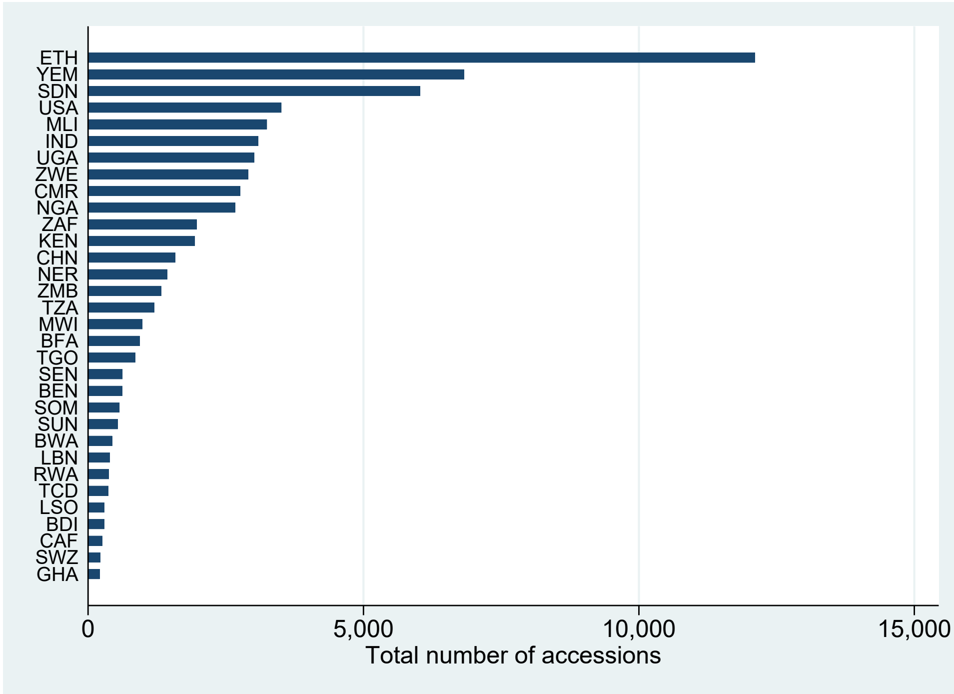

Figure A.2: *Major origins for Pearl Millet genetic material flows*

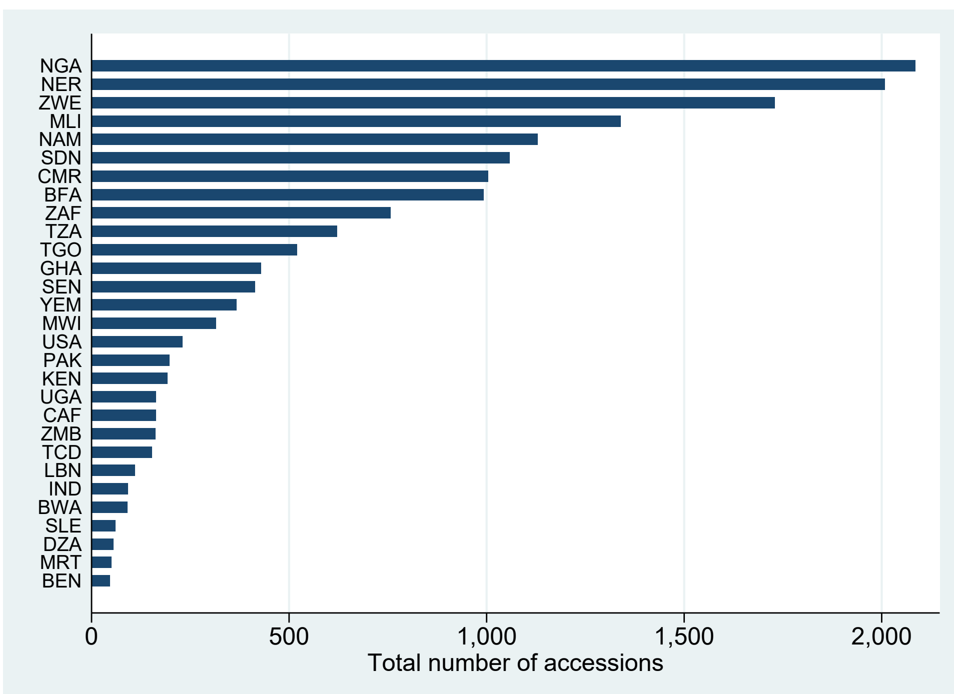

Figure A.3: *Major origins for Beans genetic material flows*

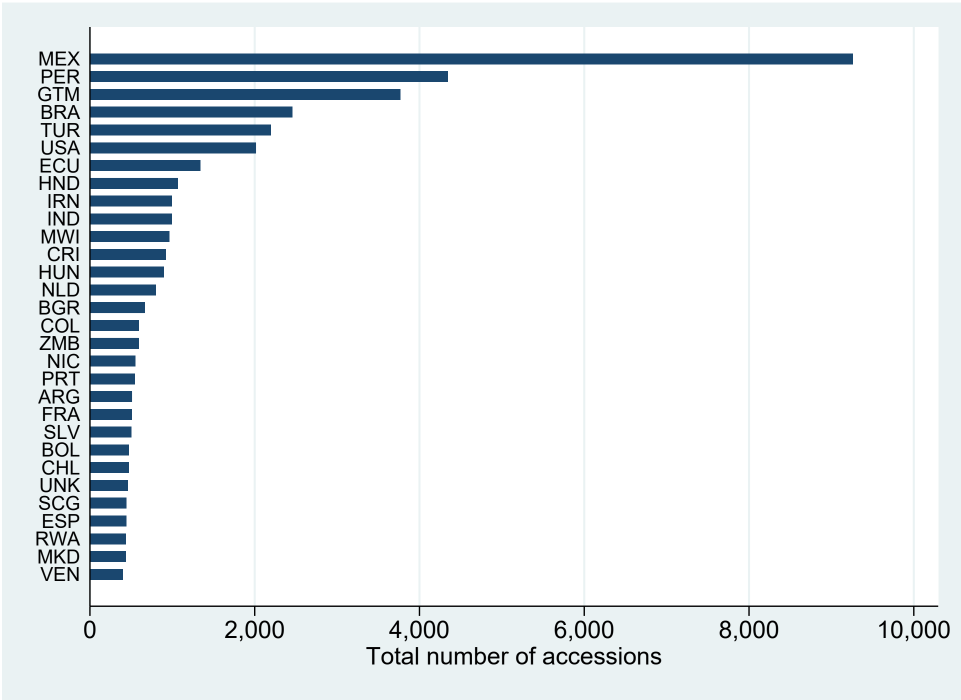

Figure A.4: *Major origins for Cowpeas genetic material flows*

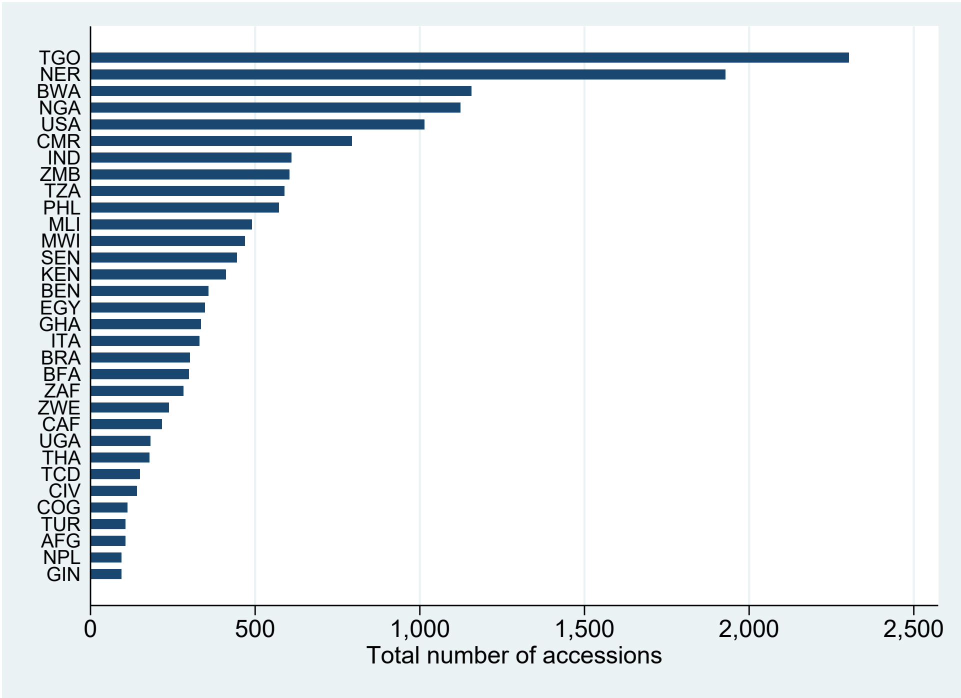

Figure A.5: *Major origins for Maize genetic material flows*

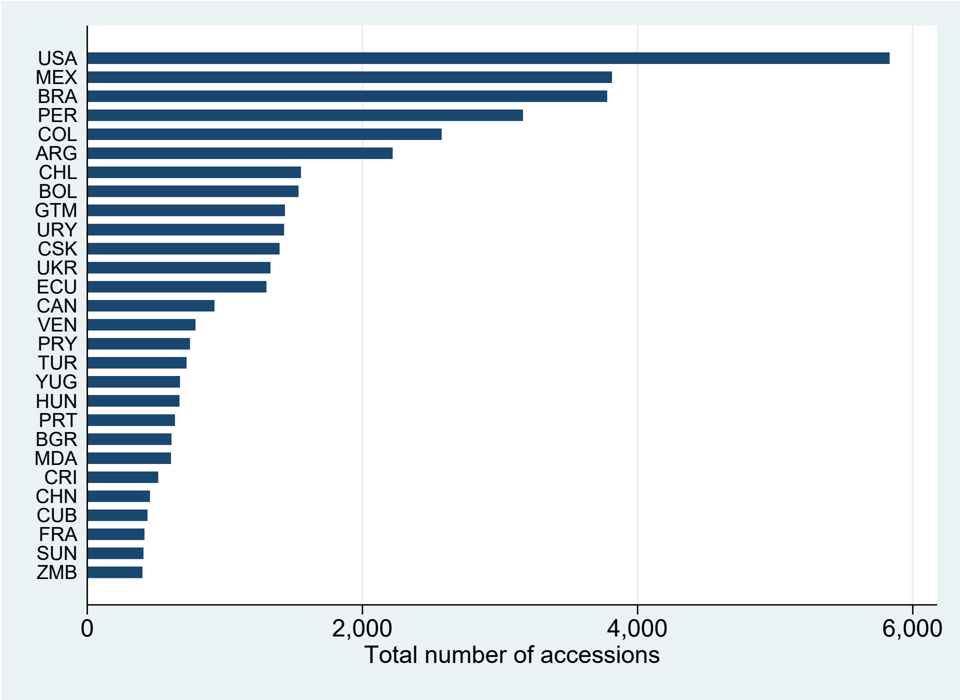

Table A.1: *Results of Panel Latent Class Negative Binomial Model for global germplasm exchanges of cow peas*

	Without splitting equation			With splitting equation		
	Coef.	SE	P-val	Coef.	SE	P-val
	Class 1			Class 1		
Constant	1.761	0.243	0.000	1.808	0.245	0.000
CBD period*Party to Neither CBD nor IT	-0.169	0.619	0.785	-0.125	0.599	0.834
CBD period*Party to CBD	-1.091	0.302	0.000	-1.094	0.295	0.000
IT period*Party only to CBD	-2.550	0.401	0.000	-2.502	0.406	0.000
IT period*Party to CBD CBD and IT	-1.732	0.325	0.000	-1.730	0.319	0.000
LOG of AREA under crop	0.048	0.025	0.054	0.040	0.028	0.158
Alpha (Dispersion parameter)	0.065	0.009	0.000	0.065	0.008	0.000
	Class 2			Class 2		
Constant	-1.490	1.742	0.393	-1.372	1.090	0.208
CBD period*Party to Neither CBD nor IT	-0.155	1.252	0.901	-0.262	1.002	0.793
CBD period*Party to CBD	-1.699	0.916	0.064	-1.735	0.543	0.001
IT period*Party only to CBD	-3.172	1.019	0.002	-3.190	0.884	0.000
IT period*Party to CBD CBD and IT	-5.837	2.101	0.005	-5.543	5.707	0.331
LOG of AREA under crop	-0.001	0.113	0.990	-0.032	0.129	0.805
Alpha (Dispersion parameter)	0.008	0.007	0.243	0.008	0.004	0.045
	Multinomial logit splitting equation					
Constant				-0.747	0.620	0.228
Arab States				-2.941	1.252	0.019
Asia and Pacific				-0.290	0.609	0.634
Europe				-2.341	0.807	0.004
The Americas				-2.122	0.845	0.012
Average land size under crop				0.219	0.070	0.002
Probability for being in class 1	0.226			0.148		
Probability for being in class 2	0.774			0.852		

Note: Africa is the base group for the region dummies.

Table A.2: *Results of Panel Latent Class Negative Binomial Model for global germplasm exchanges of beans*

	Without splitting equation			With splitting equation		
	Coef.	SE	P-val	Coef.	SE	P-val
	Class 1			Class 1		
Constant	-2.463	0.653	0.000	1.312	0.185	0.000
CBD period*Party to Neither CBD nor IT	-0.353	0.938	0.707	0.218	0.569	0.701
CBD period*Party to CBD	0.384	0.631	0.543	-0.622	0.253	0.014
IT period*Party only to CBD	1.306	0.716	0.068	0.400	0.333	0.229
IT period*Party to CBD CBD and IT	1.105	0.644	0.086	-0.613	0.299	0.041
ABS policy in place				1.244	0.429	0.004
Alpha (Dispersion parameter)	0.007	0.002	0.000	0.069	0.006	0.000
	Class 2			Class 2		
Constant	1.440	0.195	0.000	-4.473	0.458	0.000
CBD period*Party to Neither CBD nor IT	0.287	0.596	0.631	1.645	0.914	0.072
CBD period*Party to CBD	-0.630	0.264	0.017	1.943	0.614	0.002
IT period*Party only to CBD	0.573	0.341	0.093	3.311	0.727	0.000
IT period*Party to CBD CBD and IT	-0.018	0.283	0.949	2.972	0.634	0.000
ABS policy in place				0.286	1.413	0.840
Alpha (Dispersion parameter)	0.078	0.007	0.000	0.007	0.002	0.000
	Multinomial logit splitting equation					
Constant				-6.203	1.105	0.000
Arab States				-29.544	741724	1.000
Asia and Pacific				1.483	0.768	0.053
Europe				4.502	1.090	0.000
The Americas				2.719	0.771	0.000
Average land size under crop				0.423	0.081	0.000
Probability for being in class 1	0.773			0.008		
Probability for being in class 2	0.227			0.990		

Note: Africa is the base group for the region dummies.

Table A.3: *Results of Panel Latent Class Negative Binomial Model for global germplasm exchanges of millet*

	LCM With splitting equation		
	Coef.	SE	P-val
		Class 1	
Constant	-0.299	6.179	0.961
CBD period*Party to Neither CBD nor IT	-2.582	6.799	0.704
CBD period*Party to CBD	-0.043	10.664	0.997
IT period*Party only to CBD	-6.261	6.339	0.323
IT period*Party to CBD CBD and IT	0.002	11.000	1.000
Alpha (Dispersion parameter)	0.002	0.001	0.000
		Class 2	
Constant	3.010	0.159	0.000
CBD period*Party to Neither CBD nor IT	-0.966	0.485	0.046
CBD period*Party to CBD	-4.137	0.462	0.000
IT period*Party only to CBD	-4.987	0.898	0.000
IT period*Party to CBD CBD and IT	-5.679	0.473	0.000
Alpha (Dispersion parameter)	0.066	0.009	0.000
	Multinomial logit splitting equation		
Constant	-0.195	0.350	0.578
Arab States	0.815	0.652	0.211
Asia and Pacific	2.726	0.821	0.001
Europe	26.758	122119000	1.000
The Americas	3.596	1.119	0.001
Probability for being in class 1	0.99978		
Probability for being in class 2	0.00022		

Note: Africa is the base group for the region dummies.
LCM without the multinomial logit splitting equation fails to converge.

Table A.4: *Results of Panel Latent Class Negative Binomial Model for global germplasm exchanges of sorghum*

	LCM With splitting equation		
	Coef.	SE	P-val
	Class 1		
Constant	0.373	0.268	0.164
CBD period*Party to Neither CBD nor IT	-4.272	0.835	0.000
CBD period*Party to CBD	-2.877	0.365	0.000
IT period*Party only to CBD	-6.833	1.103	0.000
IT period*Party to CBD CBD and IT	-5.641	0.683	0.000
ABS policy in place	0.937	1.378	0.497
Alpha (Dispersion parameter)	0.014	0.002	0.000
	Class 2		
Constant	4.006	0.243	0.000
CBD period*Party to Neither CBD nor IT	-2.253	0.652	0.001
CBD period*Party to CBD	-1.233	0.344	0.000
IT period*Party only to CBD	-3.657	0.518	0.000
IT period*Party to CBD CBD and IT	-2.268	0.435	0.000
ABS policy in place	1.217	0.737	0.098
Alpha (Dispersion parameter)	0.070	0.006	0.000
	Multinomial logit splitting equation		
Constant	16.815	4.403	0.000
Arab States	-0.395	1.035	0.703
Asia and Pacific	0.363	1.214	0.765
Europe	-2.051	1.375	0.136
The Americas	1.998	1.158	0.084
Average land size under crop	-1.398	0.360	0.000
Probability for being in class 1	0.99987		
Probability for being in class 2	0.00013		

Notes: Africa is the base group for the region dummies.
LCM without the multinomial logit splitting equation fails to converge.

Table A.5: *Results of Panel Latent Class Negative Binomial Model for global germplasm exchanges of Maize*

	LCM With splitting equation		
	Coef.	SE	P-val
	Class 1		
Constant	-0.450	0.335	0.179
CBD period*Party to Neither CBD nor IT	-4.133	0.936	0.000
CBD period*Party to CBD	-3.556	0.467	0.000
IT period*Party only to CBD	-4.409	0.684	0.000
IT period*Party to CBD CBD and IT	-5.290	0.851	0.000
Alpha (Dispersion parameter)	0.023	0.005	0.000
	Class 2		
Constant	2.997	0.189	0.000
CBD period*Party to Neither CBD nor IT	-3.047	0.529	0.000
CBD period*Party to CBD	-3.132	0.252	0.000
IT period*Party only to CBD	-1.399	0.337	0.000
IT period*Party to CBD CBD and IT	-3.093	0.297	0.000
Alpha (Dispersion parameter)	0.094	0.009	0.000
Probability for being in class 1	0.785		
Probability for being in class 2	0.215		

Note: Africa is the base group for the region dummies.
LCM with the multinomial logit splitting equation fails to converge.