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Barriers and facilitators of access to biological material for international research: The role of institutions and networks

Federica Fusi [1,*], Eric W. Welch[1] and Michael Siciliano[2]

[1]Center for Science, Technology and Environmental Policy Studies, Arizona State University, 411 N Central Ave #750, Phoenix, AZ 85004, USA and [2]College of Urban Planning and Public Affairs, University of Illinois at Chicago, 412 S Peoria St, Chicago, IL 60607, USA

Corresponding author. E-mail: ffusi@asu.edu

Abstract

In recent years, international and national policies have intensified monitoring and control over the access, exchange, and use of biological materials. New regulative institutions addressing concerns about ownership and safety, as well as fairness and equity, are increasingly intermingled with informal practices and norms of exchange, raising the barriers to access biological materials that scientists face. Drawing from unique survey-based ego-centric network data collected from US and non-US scientists engaged in international collaborative research at the USAID Feed the Future Innovation Labs, this article investigates how regulative institutions, organizational and regional norms (meso-level institutions), and interpersonal networks facilitate or challenge access to biological materials for research. Our results show that while regulative institutions hinder access, meso-level institutions are important access facilitators in an international context. Network ties reduce the delays and blockages to access of biological material, but they do not eliminate them.

Key words: networks; international research collaboration; regulation; biological material exchange; Nagoya Protocol.

1. Introduction

The scientific enterprise has grown to a global scale as scientists tackle problems such as food security, nutrition, biodiversity, poverty, and bioterrorism that require collaboration across countries, disciplines, and sectors (Rosegrant and Cline 2003; Young et al. 2006). National and international funding agencies increasingly promote and support international collaboration to sustain scientific production, innovation, and discovery (Melin 2000). Launched in 2010, the USAID Feed the Future Innovation Labs (FTF IL) are an example of a publicly funded program that supports research to improve global food security through increased agricultural productivity, greater access to safe and nutritious food, and improved local capacity. FTF ILs encourage long-term collaboration among US and developing country scientists across a variety of sectors and institutions—universities, government research institutions, private companies, and nonprofit and nongovernmental agencies. Collaboration is expected to mobilize genetic diversity needed for agricultural research and provide innovative outputs to enhance nutrition, increase food availability, and improve agriculture resilience to climate change (Rosegrant and Cline 2003; Sanchez 2000).

Access to biological materials—livestock blood and tissues, microbes, plants, seeds, etc.—is particularly important to advance global food security research. In the case of the ILs, access to and exchange of biological materials across universities and research centers have led to the development of new varieties of plants that are more resistant to drought and other extreme climate conditions as well as the development of vaccines against animal diseases and identification of pathogen agents. Yet new institutional constraints raise concerns among public agencies and scientists involved in international research regarding access and exchange of biological materials (Cock et al. 2010; van Zonneveld et al. 2018).

Biological materials are increasingly subject to global, national, and local regulations (Bretting 2007; Sebastian and Payumo 2006; ten Kate 2002). Agreements such as the Cartagena Protocol, the Convention of Biodiversity, the Nagoya Protocol, and the International Treaty of Plant Genetic Resources for Food and Agriculture (ITPGRFA) establish new transnational requirements for accessing and exchanging biological materials, which affect scientists and research organizations (Morgera et al. 2012; Neumann 2017; Segger et al. 2013). These new regulations aim to increase fairness and equity in response to bio-piracy concerns, improve safety and security in face of bioterrorism, protect traditional knowledge, and block material transfers that might cause health and safety issues or hurt intellectual property (IP) rights

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(Kamau et al. 2010; van Zonneveld et al. 2018). However, regulations can also increase transaction costs for scientists by imposing new institutional barriers and raising administrative burdens at various levels that might constraint food security research (Esquinas-Alcazar 2005; Rosendahl 2006a,b; ten Kate and Laird 1999; Thornstrem 2012; Toledo and Burlingame 2006).

To our knowledge, the impact of this increasing regulatory complexity on the access of material inputs to research in an international setting has not been systematically explored (Rodriguez et al. 2007; Shibayama et al. 2012; Tijssen 2004; Walsh et al. 2007). Prior scholarship on international access to biological materials focuses on one-to-one exchanges or single case studies (Nijar et al. 2016; Robinson 2015; van Zonneveld et al. 2018; Yeh et al. 2017), rather than broader issues of accessibility—access, delays and stoppages—that scientists face when seeking biological materials from a variety of sources and countries. Furthermore, researchers have acknowledged the fragmented material exchange environment, which includes multiple layers of institutions and networks, but have seldom integrated these layers and investigated this complexity in an international setting. Some studies have contributed to our understanding of dyadic exchanges of research inputs (Shibayama et al. 2012) while others have focused on the institutional context but paid little attention to collaboration ties (van Zonneveld et al. 2018; Yeh et al. 2017;). Finally, although prior work has examined material exchange within the national academic context, it has rarely addressed issues faced by scientists engaged in large collaborative research across multiple countries (Walsh et al. 2007).

The main contribution of this study is to propose and test an integrative framework that considers regulations at different levels as well as the role of interpersonal networks in reducing the negative impacts of regulations on material exchange. We draw from institutional and network theory to test a framework integrating (1) regulative institutions stemming from international and national legislation; (2) meso-level institutions at the organizational and regional level; and (3) interpersonal networks of collaboration and support. We test hypotheses using data from a unique survey of US and developing country scientists who engage in genetic research in fourteen USAID-funded FTF IL program. Findings demonstrate the importance of meso-level institutions, such as organizational policies and regional proximity, in shaping access to biological material. We also show that although network structure and composition, such as relational closeness, reduce delays to access material, they do not remove blockages. While generalizability of our empirical results is limited to the global agriculture research collaborations in our sample, our theoretical framework is widely applicable across research contexts.

2. Access to biological material: an integrative framework

Our research proposes an integrative framework that investigates how regulative institutions, meso-level institutions, and interpersonal networks shape access to biological material in an international research context. While these elements can be formally independent from each other, they function as an interdependent, multilayered system that affects scientists' ability to effectively access biological material from different countries and sources (Eberlein et al. 2013; Snir and Ravid 2016). We present our framework in the next paragraphs.

Institutions, both regulative and meso, include the rules, norms, and agreements that actors are expected to follow when exchanging research inputs (Meyer and Rowan 1977; North 1990). Previous research shows that a multilayered system of institutions creates overlaps and redundancies of administrative procedures and responsibilities, which increase process inefficiencies and transactions costs that individuals experience (Djalante et al. 2011).

At the macro-level, regulative institutions stemming from international, national, and local regulation frame individual actions and choices by establishing high-order 'rules of the game' (Moraski and Shipan 1999). Regulation increasingly requires scientists to obtain formal permission for the access and use of biological material as well as to provide monetary or non-monetary returns for their use (Welch et al. 2013). For instance, material transfer agreements (MTAs) (Rodriguez 2007; Rodriguez et al. 2007) and intellectual proprietary right regimes (Hemphill 2012; Shibayama et al. 2012; Walsh et al. 2007) establish conditions for material access and exchange and assign rights on the use of biological material. While these regulations aim to ensure safety, reduce biopiracy, and promote benefit sharing, there is mixed evidence about their impact on the access and exchange of inputs for research. Eisenberg (2006) showed that IP rights have little impact on peer-to-peer data sharing as scientists are often unaware of the IP rights attached to data nor do they completely foresee the consequence of IP rights infringement. In contrast, Walsh et al. (2007) suggested that MTAs hinder access to biological material and restrict their use. More recently, Welch et al. (2017) reported that scientists perceive regulative institutions to reduce their ability to access biological material and conduct research.

Meso-level institutions are situated between regulative institutions and interpersonal networks; they are developed by organizations in response to legislation (North 1990; Scott 2013) or are informally adopted by communities and groups based on shared cultural practices (Graddy-Reed et al. 2017; Halilem et al. 2017). We consider meso-level institutions as the norms and rules implemented by research organizations—including private genebanks and natural history collections, technology transfer offices (TTOs) and patent agencies—as well as the norms and practices inherent to scientific subcultures—such as fields—or interorganizational networks (Fowler et al. 2002; Halilem et al. 2017; Schiller 2011; Shibayama et al. 2012). Meso-level institutions develop over time as individuals interact with organizations through transactions for accessing material (e.g. requests to public and private collections) or collaborate to access and exchange biological materials. Organizations can significantly shape access to material by buffering or accentuating regulative institutions, depending on whether the goals coincide (Rekers and Hansen 2015; Schiller 2011; Welch et al. 2013). Universities, for instance, can either legitimize a flexible interpretation of regulative institutions by promoting scientists' autonomy in exchanging material or they can tighten requirements regarding biological materials established by legislation (dos S. Ribeiro 2018; Halilem et al. 2017). National history collections, which have long set the standard for access and benefit sharing (ABS) of biological materials, also need to adapt to new regulatory constraints (McCluskey et al. 2017; Watanabe 2015, 2018). The interpretation of regulative requirements and their translation into protocols and procedures by collections' managers greatly affect scientists' ability to access material and might facilitate or hinder compliance with requirements of international agreements and protocols (Watanabe 2015).

Finally, interpersonal networks are established as scientists collaborate. Collaborations integrate diverse sets of human capital, but also provide access to biological materials. Walsh et al. (2007) found that 70 per cent of material exchanges occur between scientists.

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Social exchange theory and social capital theory explain how interpersonal networks can enable the exchange of resource inputs in a highly institutionalized context. Elaborated in the early 1960s from the notable work of Blau (1964), social exchange theory emphasizes how sharing 'creates diffuse future obligations, not precisely specified ones, ... [whose] nature of the return cannot be bargained about but must be left to the discretion of the one who makes it' (Blau 1964: 93–4). Social exchanges differ from economic transactions where benefits are immediately paid and negotiated. In a social exchange, the recipient receives an immediate benefit (i.e. access to resources) while the provider expects compensation at some future point (Emerson 1976; Molm 1994, 2003). Because of the undefined horizon of the transaction, social exchanges create a system of reciprocal and long-term social obligations (Cropanzano and Mitchell 2005; Shore et al. 2006). As scientists are involved in collaborative relationships, we expect social obligations to facilitate access to material.

Additionally, social capital theory argues that resource sharing is facilitated by interactions (Burt 2000; Coleman 1988; Inkpen and Tsang 2005; Nahapiet and Ghoshal 1998). Social capital is defined as 'the aggregate of resources embedded within, available through, and derived from the network of relationships possessed by an individual or organization' (Inkpen and Tsang 2005: 151). Social capital theory suggests that structural, cognitive, and relational characteristics of an individual's network matter for accessing resources—physical, symbolic, or intangible (Nahapiet and Ghoshal 1998). For instance, common norms and values embedded in strong ties reduce the exchange costs while increasing trust and perceived benefits among participants.

Figure 1 illustrates our integrative framework for access to biological material. We define access to research inputs as the ability to obtain inputs needed for research purposes with minimum delay and low likelihood of blockage. For each level, we focus on the dimensions that are relevant in the context in which FTF ILs operate. Regulative institutions include the Nagoya protocol and national, state, and local regulations, which vary across countries involved in the ILs. Meso-level institutions include norms stemming from different universities that participate in the ILs, regional proximity, and the IL research networks. Finally, interpersonal networks include both strong and instrumental ties. We develop our hypotheses in the next section.

2.1 Regulative institutions

2.1.1 International agreements: Nagoya Protocol

International agreements on biological material exchange are regulative institutions of the highest order. When ratified by a nation-state, international agreements set the framework within which regulation in member nations is established. Negotiated in 2010 and ratified so far by ninety-two countries[1], the Nagoya Protocol to the Convention for Biodiversity is an international framework that regulates access to genetic resources and aims to ensure fair and equitable sharing of benefits from the use of genetic resources[2] to the country of origin (Van Overwalle 2005). It was introduced in response to developing countries' concerns about the use of genetic resources by developed countries and the lack of benefits returned to the country of origin (Lalitha 2004; Merson 2000; Neimark 2012; Van Overwalle 2005).

The impacts of the Nagoya Protocol on access to biological material remain largely unassessed (van Zonneveld et al. 2018). Several researchers have argued that the Nagoya Protocol is likely to increase transaction costs related to the exchange and use of biological material and potentially block access (Jinnah and Jungcurt 2009; Welch 2012). Transaction costs would increase as scientists comply with the Protocol's requirements to provide adequate information on material use, track material transfers, and return adequate monetary benefits to the countries of origin. Additionally, national approaches to implementing Nagoya Protocol's ABS provisions are likely to vary significantly, creating further complexity that scientists need to navigate (van Zonneveld et al. 2018; Welch et al. 2013; Yeh et al. 2017). Finally, as the Nagoya Protocol is being introduced into an existing institutional and social system, it might create overlaps, gaps and conflicts with previous regulations and practices (Welch et al. 2013). Scientists might lack authority or be unable to provide sufficient returns for the use of the materials from others because of limitations they face in their own country. Or, provisions from the Protocol might disrupt established flows of material, which require time to adjust to new constraints. Because of the possible implications stemming from the Nagoya Protocol, we argue that:

H1: The Nagoya Protocol will negatively affect access to biological material.

2.1.2 National, state, and local institutions

Given that individual countries maintain sovereignty over regulations, access and use restrictions on biological material can vary significantly within and across countries as a function of national, state, and local regulative institutions (Cock et al. 2010). Numerous regulative institutions are established within countries to protect the rights of providers, ensure environmental safety, and protect human health. Such institutions might limit access to biological material as they place constraints on scientists by restricting third-party exchange, setting monitoring obligations and requiring quarantine of

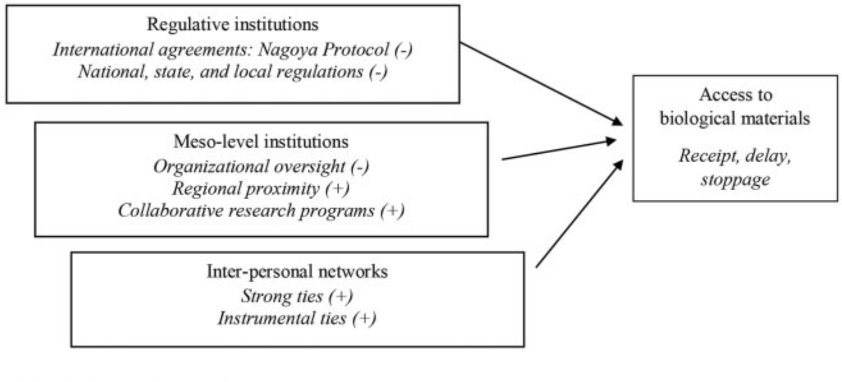

Figure 1. Integrative framework: institutions and networks.

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material, demonstration of safe containment in the laboratory, return of the material upon completion of the research, and monetary or non-monetary benefit-sharing agreements.

Increasing requirements at different government levels might result in lengthy processes and negotiations, administrative overlaps and burdens, which can delay access to research material or limit scientists' research agenda by restricting exchange of research inputs (Rodriguez 2007). Moreover, as material is exchanged across multiple actors and countries, requirements associated with regulation at national, state, and local level can create a complex web of constraints that can be difficult to manage and might hinder access to research inputs (Welch and Louafi 2014). Prior research has shown that variation in national regulative institutions can increase the complexity and transactions costs related to the exchange of biological material, and block or delay access to biological materials (Rosenthal 2006a). Furthermore, scientists are often unaware of or lack expertise about local regulatory regimes, which further increase the complexity and difficulty of navigating regulative institutions within and across countries (Hemphill 2012; Walsh et al. 2007). Because rule complexity, administrative procedures and compliance with national, state, and local regulation demands may block or delay access to biological materials (Eisenberg 2006; Rosenthal 2006), we argue:

H2: National, state, and local regulations on biological materials will negatively affect access to biological material.

2.3 Meso-level institutions

2.3.1 Organizational policies: oversight of access, exchange, and use

Designed by universities and research centers, organizational oversight policies establish rules, agreements, or other procedures that affect access, exchange, and use of biological materials among scientists (Reichman et al. 2011; Uhlir and Schröder 2007). Many organizations are concerned about the protection of IP and other ownership rights on biological material (Walsh et al. 2007) and establish rules and procedures for material exchange and use. Universities, for instance, regulate exchange and use of biological material through common MTAs that specify conditions for transferring material to collaborators in other organizations.[3] These policies aim to ensure researchers' compliance with university IP claims as well as regulative institutions.

Previous research has shown mixed findings on the effect of organizational policies on the exchange of research inputs. Some studies on data sharing found that organizational policies positively impact access and use of research inputs as they reduce transaction costs and rationalize competitive pressures and commercial interests (Cabrera and Cabrera 2002; Campbell and Bendavid 2003; Mowery and Ziedonis 2007). In particular, organizational policies help scientists for dealing with funding requirements and avoid commercial losses (Campbell and Bendavid 2003). By contrast, other studies found that organizational authority creates rigid structures and procedures that discourage scientists from collaborating, sharing, or adopting entrepreneurial behavior (Halilem et al. 2017). Moreover, when the exchange of resources is based on formalized rules, rather than informal norms of reciprocation, actors might be less likely to develop interpersonal trust (Molm 1994).

We suggest that in an international setting, autonomy will play a particularly important role and organizational policies will tend to hinder access to material. When organizations actively control material exchanges, they limit the autonomy of individuals to select partners, conditions, and resources to exchange (Eisenberg 2006; Mowery and Ziedonis 2007). Under strict university controls, scientists may not be allowed to negotiate individual agreements with their colleagues or they may not be authorized to provide material or other benefits in return. By contrast, organizations that promote scientists' autonomy legitimize flexible interpretations of and responses to the broader policy environment by allowing scientists to more effectively negotiate conditions of exchange, concede benefits to their counterparts, and rely on informal shared norms and non-monetary benefits. For instance, scientists might offer collaboration and involvement in research projects as non-monetary returns that scientists can derive from providing access to material (Welch 2012). Thereby we propose that:

H3: Organizational policies of oversight will negatively affect access to biological material.

2.3.2 Regional proximity

While regulative institutions and organizational policies suggest an increasingly fragmented institutional environment, there is evidence that geographical proximity promotes the convergence of formal and informal rules that regulate collaborative research and cross-border relationships, including material exchange (Rekers and Hansen 2015). We argue that regional proximity helps leverage common resources and relationships, and encourages behaviors that buffer the impacts of regulative institutions. Moreover, institutional isomorphism (DiMaggio and Powell 1983; Snir and Ravid 2016) suggests that neighboring countries will be more likely to develop similar norms and institutions because regional proximity creates social and institutional pressures that encourage uniformity. We discuss these mechanisms in the next paragraphs.

First, neighboring countries are likely to share similar environmental and biological contexts and issues, such as plant or animal diseases, climate conditions, or geological characteristics (Görg and Brand 2000). The existence of common problems creates incentives for collaborating and pooling resources and increases positive perceptions about collective efforts. Researchers have shown that the number of transnational research networks has increased in past twenty years to face common problems across neighboring countries, such as the spread of diseases or improvement of key regional crops (Plucknett and Smith 1984; Roseboom et al. 1998). Those inter-regional initiatives allow countries and research organizations to reduce the high start-up costs of research, share infrastructure, material and other resources, avoid duplication of research efforts, and facilitate transfer of technology and knowledge (Cock et al. 2010; Plucknett and Smith 1984). This is particularly important in developing countries where many research centers lack human and technical capacity for conducting genetics and genomics research, and have limited access to financial resources (Knoben and Oerlemans 2006).

Second, research organizations are promoting transnational region-based meetings and forums that encourage collaboration and sharing across geographically close scientists (Anderson 1998). Regional proximity facilitates face-to-face interactions, which promote exchange of knowledge and practices across scientists (Knoben and Oerlemans 2006). Frequent interpersonal and inter-institutional relationships are likely to promote the development of shared social norms and practices, common values, and trust (Rekers and Hansen 2015). These findings from prior research were confirmed by interviews that we undertook with IL scientists in the first stage of this

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research project (Welch et al. 2017). In the interviews, developing country scientists consistently reported that regional proximity promotes the development of formal and informal institutions that mediate and facilitate cross-border exchange of biological materials among organizations and between scientists.

Finally, as a result of those mechanisms, countries in the same region are more likely to develop similar ABS rules, biosecurity requirements and other regulations that expedite material access and exchange within the region, as compared to with other regions. As suggested by institutional isomorphism, organizations will tend to replicate policies of nearby organizations because of social and institutional pressures (DiMaggio and Powell 1983; Snir and Ravid 2016). Taken together, these mechanisms suggest that common problems, joint regional initiatives, and collaboration networks that establish common norms, build trust and create similar formal mechanisms will promote access to biological material. Therefore:

H4: Regional proximity will positively affect access to biological material.

2.3.3 Collaborative research programs

Research programs establish collaboration networks that connect multiple organizations within and across countries to carry out common research goals. Similar to the rationale presented for regional proximity above, research programs are likely to provide important synergies, common resources, and relationships which help scientists address regulatory complexity and barriers associated with the exchange of materials needed for research. Continuous collaboration across organizations leads to the development of shared norms that regulate and facilitate collaboration and sharing (Lawrence et al. 2002). Moreover, research programs take the advantage of access to complementary resources across network members to overcome barriers that may be created by organizational policies or national, state, and local institutions (Muriithi et al. 2017).

USAID FTF ILs are an example of a research program that promotes collaboration networks among US and developing country scientists. In the case of the FTF ILs, research activities are allocated across participating research institutes in different countries based in part on their ability to access needed material. Entities that are part of the FTF ILs are more likely to share material and develop common agreement for the usage of propriety research inputs among partners. Such agreements reduce complexity and increase certainty of access to material. As such, we expect that scientists will report lower barriers to access when access material from countries that are partners of the FTF ILs program as compared to countries not involved in the research program.

H5: Exchange with countries in the same collaborative research networks will positively affect access to biological material.

2.4 Interpersonal networks

Individuals develop different types of network ties; a classical division exists between strong ties and instrumental ties (Lincoln and Miller 1979). Tie strength reflects the emotional intensity, intimacy or mutual confiding, and reciprocity of the relationship (Granovetter 1973). Instrumental ties provide access to advice and information needed for the completion of a task or activity (Balkundi and Harrison 2006; Lincoln and Miller 1979). We develop separate hypotheses for strong and instrumental ties.

2.4.1 Strong ties

The strength of ties is a salient characteristic of the relationship between two individuals. Given the collaborative context in which scientists are embedded, we suggest that individuals in a strong relationship will be more likely to exchange resources (Lin 2001). Particularly, close colleagues may be more willing to exchange resources or help accessing biological materials, even when access is formally restricted or controlled by international and national regulations or industry competition.

Researchers will be more willing to transfer materials to close colleagues due to the higher trust and reciprocity inherent to strong ties. Trust—'the faith that an [unwanted] event or action will not occur' (Lin 2001: 147)—reduces concerns about misappropriation of materials or misbehavior of the recipient. Greater confidence in reciprocity increases scientists' long-term likelihood of obtaining returns—material, data, technical, or other resources—for the provision of material (Lin 2001; Shibayama and Baba 2011). Prior work is suggestive: scientists are more willing to share resources with collaborators who are also friends or trusted colleagues (Shibayama and Baba 2011) where pathways for access to genetic materials are mostly informal (Welch et al. 2013). For these reasons, we expect that trust and reciprocity will reduce transaction costs, particularly those associated with monitoring and negotiation, and increase the likelihood and richness of resource and knowledge exchange (Hoang and Antoncic 2003; Larson 1992; Saxenian 1991). As such we suggest:

H6: Strong ties will positively affect access to biological material.

2.4.2 Instrumental ties

Relationships among scientists are often instrumental as they facilitate access to skills, knowledge, and other research inputs required for the pursuit of scientific activities (Bozeman and Corley 2004). Melin (2000) found that while tie strength is a reason to collaborate, it is rarely the only one: often scientists collaborate with scientists who have 'special competences' or 'special data or equipment', or promise benefits such as 'increasing knowledge' or 'contacts and connections for future work' (pp. 34–5).

In an international research environment, we expect that scientists will build relationships where the primary content of exchanges is advice, information, guidance, or support that they are not able to draw from their own experience or from pre-existing relationships. In particular, scientists might seek information and knowledge about regulations, administrative procedures, organizational practices, and strategies that can increase their likelihood of obtaining needed resources. Instrumental ties could also provide access to individuals in other countries who might act as facilitators or provide direct access to genetic resources. Given the complexity of the international environment, we argue that instrumental ties will help navigate multiple institutions at the international, national, and local level and facilitate access to biological materials. Therefore, we hypothesize:

H7: Instrumental ties will positively affect access to biological material.

3. Data and method

3.1 Research setting

The USAID FTF program includes twenty-four Innovation Labs (ILs) where scientists collaborate across seventy US universities and

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nineteen partner countries in Africa, Asia, Latin America, and the Caribbean. US universities are selected as host institutions for the ILs, but research goals are collectively negotiated and coordinated between US and non-US scientists, and between IL members and USAID program managers. The ILs primary research goals include: advancing productivity (i.e. breeding and genetics for crops and livestock or vaccine development), transforming production systems (i.e. research on agriculture, economics, land and trade policy, and management), and enhancing nutrition and food safety (i.e. food quality and accessibility for vulnerable populations). Additional project goals can include gender integration, improvement of local nutrition, private sector advancement, and capacity building.

Given their international scope, FTF ILs offer a unique opportunity to study institutional constraints on materials that might arise as results of regulative and meso-level institutions, and the role of interpersonal networks. Scientists involved in the ILs are expected to conduct international research across several sectors and organizations, and to collaborate with a broad network of scientists. Biological material is an important input to research for scientists working on breeding, vaccine and variety development, disease resistance, and crop resilience.

3.2 Data collection

Data were collected in two stages. In the first stage, the research team conducted seventy-seven semi-structured interviews with US and non-US researchers working in five selected ILs covering both animal and plant biological material (Welch et al. 2017). Interview questions sought to collect qualitative data on the use of biological material inputs for scientific collaboration; administrative and regulatory barriers encountered by researchers; biological material exchange flows; and benefit sharing opportunities. The interviews were used to inform the survey instruments and provide qualitative insights to help the interpretation of survey results.

In the second stage, we targeted the sixteen FTF ILs involved with genetic research to conduct a survey of active scientists (e.g., scientists currently conducting research as part of the IL). Two FTF ILs were excluded for different reasons as we moved forward with our survey: one IL had only recently been funded and was not effectively functional and one was unable to provide contact information of its members as requested. Table 1 describes the fourteen ILs which have been included in our study. We include information on the host US university, partner countries, and number of members.

The survey collected behavioral and perceptual data on biological material sources, access, exchange, and use practices; regulatory and rule-based constraints on access, exchange, and use; returns or benefits from the access to and use of biological materials, investments in RandD, and other relevant topics; and trends and impacts of regulations and rules on research activity.

A survey section was dedicated to collect social network data about scientists' collaborators and material exchange. Network data were collected using two types of questions: name generator and name interpreter questions. Name generator questions ask respondents to identify key individuals. Name interpreter questions ask respondents questions about the characteristics of and their relationships with the individuals they identified.

We first provided respondents with a roster list of members from their IL and asked them to indicate with which members they interacted in the past two years. We defined interaction as 'email exchanges, phone or Skype calls, video and teleconferences or face-to-face meetings to specifically discuss your research [excluding] interaction through listservs'. Then, we ask two open-ended name generator questions. In the first question we asked: 'In the past two years, who else have you collaborated with on your research? Please identify up to ten researchers outside your Innovation Lab, either in your country or outside your country.' In the second question, we asked 'Other than the people you named so far, from which other people did you request genetic materials over the past two years?

Table 1. FTF IL.

ILs	Host university	Partner countries	# Member scientists
Applied Wheat Genomics	Kansas State U.	Bangladesh, India, Pakistan	5
Aquaculture and Fisheries	Oregon State U.	Bangladesh, Cambodia, Ghana, Kenya, Nepal, Philippines, Tanzania, Uganda, Vietnam	66
Climate-Resilient Beans	Pennsylvania State U.	Colombia, Honduras, Malawi, Mozambique, Tanzania, Zambia	18
Climate-Resilient Chickpea	U. California, Davis	Ethiopia, India, Turkey	24
Climate-Resilient Cowpea	U. California, Riverside	Burkina Faso, Ghana, Nigeria, Senegal	9
Climate-Resilient Millet	U. of California, Davis	India, Mali, Nigeria	4
Climate-Resilient Sorghum	U. of Georgia	Ethiopia, India, Kenya, Mali, South Africa	13
Genomics to Improve Poultry	U. of California, Davis	Ghana, Tanzania	11
Grain Legumes	Michigan State U.	Benin, Burkina Faso, Ghana, Guatemala, Haiti, Honduras, Malawi, Mozambique, Niger, Senegal, Uganda, Zambia	51
Integrated Pest Management	Virginia Tech U.	Bangladesh, Cambodia, Ethiopia, Kenya, Nepal, Tanzania, Vietnam	113
Peanut Productivity and Mycotoxin Control	U. of Georgia	Burkina FTaso, Ghana, Haiti, Malawi, Mozambique, Niger, Senegal, Uganda, Zambia	117
Rift Valley Fever Control	U. of Texas, El Paso	Tanzania	11
Sorghum and Millet	Kansas State U.	Burkina Faso, Ethiopia, Mali, Niger, Senegal	57
Soybean Value Chain	U. of Illinois	Ethiopia, Ghana, Malawi, Mozambique, Zambia	24

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Please identify up to five individuals.' Once names were generated, the survey asked a set of name interpreter questions including network members' country, organization of employment, length of relationship, friendship, type of collaboration, and resource exchange. The resulting ego-centric network data include the structure and composition of the research networks.

3.2.1 Survey administration

Information on active researchers were collected on FTF IL websites and confirmed with the Principal Investigator. The final list, cleaned for duplicates and unreachable members, included 503 members. The survey was administered online using Sawtooth software, a platform for designing personalized web-based surveys. The software allowed us to engineer in branching according to a respondent's nationality, use of biological material, research field and network responses. A survey pretest was conducted with twenty randomly selected FTF IL members to ensure survey functionality. The full survey was open from 10 May to 3 July 2016. The research team sent five weekly reminders to all survey respondents. All invitations, reminders, and other communication with respondents were conducted via email. The survey required 25–30 min to complete.

We received 339 total responses (306 complete and 33 partial responses). After removing fifty-three respondents who were judged 'ineligible' because they self-identified as non-active researchers (i.e. retired or no longer members). An additional twenty-five respondents were removed because they completed less than 50 per cent of the survey. We adjusted the sample frame to account for individuals who were unreachable, retired, or inaccessible, resulting in a final sample of 261 scientists. The weighted survey response rate is equal to 64 per cent (APPOR RR4 2016). In the analysis, we include only the 209 researchers who reported using biological for research—80 per cent of the final sample.

3.3 Dependent variable

Our dependent variables capture individual level responses about access to biological material for research across countries. Dillman et al. (2014) suggest that survey questions need to clearly define the domain of interest to facilitate the response task to survey respondents, including recalling information from memory and judging information relevance. For such reasons, we designed a two-step question that grounds respondents' answer into country-specific context. The first question asked: 'Which countries are the most important sources of genetic materials for your research?' Respondents were invited to indicate up to five countries.[4] Then, for each country indicated, we asked the respondent three separate questions:

- What is the likelihood that you will receive the genetic material that you request from individuals or organizations in each of these countries? (Obtain)
- What is the likelihood that you will not receive genetic material you request because of rules and regulations in each of these countries? (Stoppages)
- What is the likelihood that there will be significant delays in receiving the genetic material that you request because of rules and regulations in each of these countries? (Delays)

Using this data, we constructed three different variables to measure access to biological material: likelihood of receiving biological material (Likelihood Receipt), likelihood of not obtaining biological material (Likelihood Stoppages) and likelihood of significant delay (Likelihood Delays). Each country was ranked by respondents on a scale from 1 = Very Unlikely to 4 = Very Likely. We construct our dependent variables by averaging the reported likelihoods across all the countries named by the respondent. As result, we obtain three continuous variables ranging from 1 to 4. A high score for the variable Obtain indicates that scientists face low barriers to access biological material. A high score the variables Stoppages or Delays indicate high barriers to access biological material.

Approximately 16 per cent of the selected sample contained missing values for one or more of our dependent variables. We compared respondents versus non-respondents and found no statistical differences in terms of the type of biological material utilized (animal, plant, insect, and microbe) and country of origin (developing vs developed countries). We found only a slightly significant difference ($P < 0.1$) for the dependency variable (see description below), suggesting that scientists who report lower dependence on external sources of material were less motivated to reply to those questions. It could be that those scientists do not engage in international exchange because they primarily use their own biological material.

3.4 Independent variables

3.4.1 Regulative institutions

Nagoya Protocol is calculated as the percentage of the countries identified by the respondent as important for his or her research that had ratified the Nagoya Protocol at the time of the survey. Data on ratification of the Protocol were collected on the Conventional of Biodiversity website.[5] On average, half of the countries identified by respondent were signatories of the Nagoya Protocol (mean = 0.48; SD = 0.31).

National, state, and local regulation (National Regulation) is an averaged Likert scale-based variable that measures how frequently respondents are required to comply with different types of rules, regulations or administrative requirements including (1) 'National (or federal) biosafety regulations in your country'; (2) 'Other national (or federal) government regulations in your country'; (3) 'State, province, district, or local government regulations in your country'; (4) 'ABS regulations in other countries'; (5) 'Other national (or federal) government regulations in other countries'; and (6) 'State, province, district, or local government regulations in other countries'. Answer options range from 1 = 'Never' to 5 = 'Always'. The items have a Cronbach's alpha of 0.87 (mean = 3.18, SD = 1.35).

3.4.2 Meso-level institutions

Organizational Oversight measures the extent to which scientists' organizations grant them autonomy or oversee material exchange. It is a composite scale of two items asking respondents whether they agree or disagree with the following statements about their primary work organization: (1) 'I have the autonomy to decide whether or not to provide genetic materials' and (2) 'I have flexibility in negotiating terms and conditions under which I transfer or receive genetic materials.' The scale ranges from 1 = 'Strongly agree' to 5 = 'Strongly Disagree'. A high score indicates greater organizational oversight. The Cronbach alpha is 0.75 (mean = 2.9, SD = 1.05). Regional Proximity measures the degree to which respondents need materials from countries that belong to the same geographical region as compared to countries that belong to different geographical regions. The index is calculated using Krackhardt and Stern (1988) formula:

$$(IG - EG) \ / \ (EG + IG)$$

Whereas IG (internal to geographical region) represents the number of countries within the respondent's geographical region and EG

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(external to geographical region) represents the number of countries outside the respondent's geographical region. Geographical regions were defined according to FAO definition of world regions.[6] When positive, the index indicates that respondents have a greater reliance on biological material from countries inside their region. When negative, the index indicates that respondents require more biological material from countries outside their geographical region. The average index is −0.29 indicating an overall dependency on countries outside their region for access to biological material. Collaborative Research Network measures the proportion of countries, among the five indicated by the respondent, that are among FTF IL partner countries. They include: Bangladesh, Cambodia, Ethiopia, Ghana, Guatemala, Haiti, Honduras, Kenya, Liberia, Malawi, Mali, Mozambique, Nepal, Rwanda, Senegal, Tajikistan, Tanzania, Uganda, and Zambia. On average only one-third of the countries identified by respondents are USAID partner countries (mean = 0.33, SD = 0.3).

3.4.3 Interpersonal networks

We measure strong ties using two variables, Communication and Friendship. We suggest that in an international collaborative research project, it is useful to distinguish two types of strong ties: emotional strong ties and high frequency strong ties. Emotionally strong relationships exist between friends. High frequency relationships exist between collaborators who communicate often to coordinate research project activities. Frequent communication increases trust among scientists, but because trust is even higher among friends, we expect that friendship will facilitate exchange more than frequent ties. Communication is calculated by averaging the frequency of communication across all collaborators in the network. Communication was measured by asking respondents to indicate for each collaborator *how frequently do you communicate with the people you identified?* Responses range from 5 = Weekly, 4 = Monthly, 3 = A few times a year, 2 = Once a year, 1 = Less than once a year. The mean is 3.51 (SD = 0.57). Friendship is the proportion of close ties within each respondent's network. We asked respondents to indicate for each collaborator whether she or he was a 'close friend'. The variable ranges from 0 to 1, the average is 0.25 indicating that one out of four ties is with a friend. The low correlation between Friendship and Communication suggest that is important to treat them as two different constructs. We measure instrumental ties by asking respondents: 'Do you rely on any of the people you identified to help you address international regulations or permits?' Help with regulation is a network variable that measures the proportion of collaborators from which respondents receive help to navigate international regulations and permits (range from 0 to 1). On average, respondents indicate relying on 21 per cent of individuals in their network to address international regulations (SD = 0.2).

3.5 Control variables

We control for country where the scientist works, his or her position, type of organization, dependency on external sources for access to biological material, and type of biological material. Developing Country codes whether a scientist is currently working in a developing country (=1) or a developed country (=0). We identify developing countries by using the classification provided by the FAO statistical unit.[7] Almost all FTF IL scientists from developed countries are US scientists. Junior Scientist codes whether a scientist is in a junior position (assistant professor or post-doctoral researcher =1). Private is a control variable that indicates whether a scientist works for a private sector organization (=1) or a public organization, including universities or colleges, international agricultural research institutes and public research organizations, centers or institutes (=0). We expect scientists who working in private organizations will encounter greater barriers to access biological material due to application of IP rights and commercial agreements (Gans et al. 2017; Walsh et al. 2007). Dependency is a continuous variable scaled from 0 to 1 that measures how much the scientist is reliant on external sources for accessing biological material for his or her research. We asked respondents to indicate what percentage of biological material they obtain from their own personal collection. At one end of the scale (=0) Dependency indicates that the scientist relies only on her own collection and therefore might have little to no need of accessing material from external sources. At the other end of the scale (=1) Dependency indicates that the scientist accesses all necessary biological material from external sources.

Finally, we asked respondents to indicate which type of biological material—plant, animal, microbe, or insect—they use for their research. So as to not saturate the model, given the small number of observations, we consider only two categories. Plant is a dummy variable that identifies respondents who use only plant biological material (=1, 0 otherwise). Animal is a dummy variable that identifies respondents who use only animal biological material (=1, 0 otherwise). We expect that scientists utilizing only plant or animal biological material will be more affected by regulation as compared to scientists utilizing microbes or insects (Welch et al. 2013). Agricultural plant material is the central focus of the ITPGRFA, while animal material is more affected by biosafety and endangered species regulations. A total of 39 per cent of respondents utilize only plant material and 6 per cent of them utilize only animal material. Descriptive statistics of our variables are presented in Table 2. Correlation coefficients for all variables are provided in Table 3.

4. Analysis and results

4.1 Model

Because the dependent variables are continuous scales constrained to a limited range (i.e. from 1 = very unlikely to 4 = very likely), using an ordinary least squares (OLS) linear model might provide biased estimates (Greene 2000; Long 1997). Biased estimates are the result of a floor and ceiling effect that are typical of survey responses that utilize Likert type scales; because of the formulation of the item content, only a limited number of categorical responses are provided to respondents which prevent from observing the distribution of extreme low or high values (Long 1997). In fact, respondents' replies tend to accumulate at the two extremes of the scale (e.g., 'very likely' and 'very unlikely') and the variable shows a doubly censored distribution.[8]

Thus, we utilize a generalized version of the TOBIT model (Tobit 1958) which is appropriate when examining a limited dependent variable that is censored on both sides and therefore presents spikes at the censored ends. In our case, the exact values of our dependent variable are only known in an interval that is defined by both left (=1) and right (=4) limits. We can express it in the following way:

$$y_i^* = x_i\beta + e_i$$

$$y_i = \begin{Bmatrix} a & \quad if\ y_i^* \leq a \\ y_i^* & if\ a < y_i^* < b \\ b & \quad if\ y_i^* \geq b \end{Bmatrix},$$

where $a = 1$ and $b = 4$.

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Table 2. Descriptive statistics.

Dependent variables	*N*	Mean	SD	Median	Min	Max
Likelihood Receipt	172	3.52	0.59	3.67	1	4
Likelihood Stoppages	162	1.9	0.82	2	1	4
Likelihood Delays	160	2.47	0.9	2.5	1	4
Regulative institutions						
Nagoya Protocol	173	0.48	0.31	0.5	0	1
National Regulation	191	3.18	1.35	3	1	5
Meso-level institutions						
Organizational Oversight	188	2.9	1.05	3	1	5
Regional Proximity	173	0.29	0.68	0.5	−1	1
Collaborative Research Networks	173	0.33	0.3	0.33	0	1
Interpersonal networks						
Communication	203	3.51	0.57	3.55	1.5	5
Friendship	205	0.25	0.29	0.12	0	1
Help with Regulation	205	0.21	0.2	0.16	0	1
Control variables						
Developing Countries	205	0.66	0.48	1	0	1
Junior	196	0.27	0.44	0	0	1
Private	194	0.06	0.24	0	0	1
Dependency	205	0.19	0.33	0	0	1
Plant	205	0.39	0.49	0	0	1
Animal	205	0.06	0.24	0	0	1

Table 4 shows results from our analysis.[9] All three models are associated with a P-value <0.001 as compared to a null model or a model containing only control variables when performing a likelihood ratio test; therefore, the presented models are an improvement as compared to naïve models.

4.2 Hypotheses testing

We find significant evidence that the Nagoya Protocol, Organizational Oversight, Regional Proximity, and Collaborative Research Networks influence access to biological material, thereby supporting our hypotheses 1, 3, 4, and 5. Results also show partial support for network hypotheses 6 and 7. Communication increases the likelihood of obtaining biological material, while Help with Regulation reduce stoppages and delays. Friendship only significantly reduces delays. Discussion of these findings follows.

4.2.1 Regulative institutions

Results show that requesting materials from countries that have ratified the Nagoya Protocol decreases the likelihood of obtaining biological material ($P < 0.001$) and, similarly, increases the likelihood of not receiving biological material from individuals or organizations ($P < 0.05$). This suggests that international agreements and ABS regimes are resulting in barriers to access of biological material as suggested in hypothesis 1. However, we found no evidence that requesting materials from countries that ratified the Nagoya Protocol increases delays for receiving biological materials. It could be that the Protocol's primary effect is simply to halt material exchange and that requests either do not enter an administrative process or that if material access is granted the administrative process is, on average, smooth.

We find no significant effect of the national, state and local regulation on access to material (Hypothesis 2). The National Regulation variable is not statistically significant ($P > 0.05$) in all three models. Contrary to our hypothesis, it could be that scientists are aware of and know how to navigate national, state, and local regulation, such that these institutions do not constitute a barrier to material exchange.

4.2.2 Meso-level institutions

Organizational Oversight is statistically significant across all three models, suggesting strong support for hypothesis 3 that organizational policies affect both access to and process of obtaining biological materials. Scientists who have greater negotiating autonomy are more likely to obtain the biological materials they need ($P < 0.01$) and are less likely to encounter stoppages ($P < 0.001$) or delays ($P < 0.01$). The magnitude of the effect is similar for Likelihood Receipt and Delays but slightly greater for Stoppages. We conclude that organizational oversight policies have a significant, negative effect on access to biological materials.

Regional Proximity is also significant across the three models, confirming our hypothesis 4. Scientists who need to access resources from countries outside their region are less likely to obtain biological materials ($P < 0.05$) and more likely to encounter stoppages ($P < 0.05$) or delays ($P < 0.01$) as compared to scientists who mostly access biological material from countries inside their region. Finally, Collaborative Research Networks have a positive effect on receiving biological materials ($P < 0.01$) and a large negative effect on stoppages ($P < 0.001$): scientists exchanging more with FTF partner countries are more likely to obtain material and less likely to encounter stoppages. This confirms our expectations in hypothesis 5.

4.2.3 Interpersonal networks

Hypothesis 6 suggested that strong ties are positively related to access to biological material. Strong ties—Communication and Friendship—do not affect likelihood of encountering stoppages when receiving biological materials. However, higher Communication has a positive effect on the likelihood of receiving biological material ($P < 0.05$) suggesting that individuals who communicate frequently, for instance because they are collaborating on the same projects, are more likely to help each other in material

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Table 3. Correlation table.

2	Likelihood Receipt	Likelihood Stoppages	Likelihood Delays	National Regulation	Nagoya Protocol	Organizational Oversight	Regional Proximity	Communication	Friendship	Help with Regulation	Coll. Res. Net.	Developing Countries	Junior	Private	Dependency	Plant	Animal
Likelihood Receipt	1																
Likelihood Stoppages	−0.56**	1															
Likelihood Delays	−0.35**	0.46**	1														
National Regulation	0.10	0.07	0.10	1													
Nagoya Protocol	−0.12	0.02	−0.12	−0.03	1												
Organizational Oversight	0.17*	−0.22**	−0.14	−0.13	−0.13	1											
Regional Proximity	−0.19*	0.21**	0.18*	0.07	−0.15*	0.01	1										
Communication	0.17*	−0.02	−0.08	0.01	−0.07	0.08	0.13	1									
Friendship	0.07	−0.04	−0.18*	−0.03	0.17*	−0.01	−0.13	0.11	1								
Help with Regulation	0.13	−0.10	−0.08	0.15*	0.04	−0.07	0.02	0.11	0.13	1							
Coll. Res. Net.	0.14	−0.26**	−0.06	0.04	0.37**	−0.00	−0.24**	−0.05	−0.08	0.00	1						
Developing Countries	0.12	0.02	0.13	0.12	0.02	−0.13	−0.32**	0.03	0.19**	0.09	−0.08	1					
Junior	0.06	−0.08	−0.09	0.03	0.06	−0.11	−0.05	0.06	0.02	0.06	−0.04	0.15*	1				
Private	0.07	−0.05	−0.07	−0.04	−0.08	0.10	−0.16*	0.06	−0.03	−0.04	−0.02	0.14	0.09	1			
Dependency	0.05	0.19*	0.08	−0.10	−0.03	0.06	−0.07	−0.05	−0.01	0.00	−0.05	0.06	−0.02	0.11	1		
Plant	−0.13	−0.05	−0.18*	−0.05	0.15	−0.07	−0.03	−0.13	0.02	−0.16*	0.00	−0.06	0.00	0.00	−0.15*	1	
Animal	0.02	0.03	0.16*	−0.06	−0.17*	0.07	−0.05	0.17*	0.08	0.06	0.15*	0.10	−0.11	−0.07	0.09	−0.21**	1

Significance levels: *$P < 0.1$; **$P < 0.05$.

exchanges. Friendship significantly decreases delays in receiving biological material ($P < 0.05$). It could be that while close ties cannot undermine regulations, they put more efforts in helping their friends to receive material on time. Finally, we also found partial support for hypotheses 6 on instrumental ties. Help with Regulation does not affect likelihood of receiving materials or stoppages, but we found a negative correlation with delays ($P < 0.05$) suggesting that receiving help to deal with regulation might increase the efficiency of the exchange process and reduces the likelihood of delay.

4.2.4 Control variables

Among control variables, we found some slightly significant differences across genetic resource types, with scientists working on plants less likely to incur delays as compared to scientists working with other types of genetic resources (i.e. microbes, insects, animals). It also appears that scientists who are more dependent on external sources of biological material are more likely to encounter stoppages, probably because they submit a higher number of requests, and that scientists in developing countries are more likely to encounter delays as compared to scientists in developed countries.

5. Conclusion

To contextualize the discussion of our findings, we first acknowledge several limitations of our study. Because data are from respondents who participate in the FTF IL, generalizability beyond the FTFs should be done with care. FTF ILs have multiple goals including knowledge creation, enhancement of research capacity, female empowerment, improvement of farmer livelihoods, and economic development. While the FTF ILs do not always accomplish all of these goals (Elliot and Dunning 2016; Munoz and Tumusiime 2015), for the purposes of our study it is important to note that ILs may have some unique characteristics. Other global research programs and projects may not have the same goals or they may be organized in very different ways to accomplish them. Similarly, because the scientists who responded to the survey are mostly from USA and other partner countries in Africa, we caution against generalizing our findings to other world regions, such as Asian or South American countries.

With respect to our data, we recognize that dependent variables report scientists' perceptions on access to biological material. Respondents may over- or under-report the actual barriers resulting in some measurement bias. Nevertheless, perceived efficacy of obtaining material is an important determinant of scientists' behavior: those who register difficulty in accessing biological material are more likely to encounter higher costs to research, and are more likely to stop a research project or switch research topics (Welch et al. 2017). Additionally, while we consider both national regulation and regional and organizational constraints, we have limited information about the content of local, state, and national regulation, organizational policies and the forms of regional collaboration. Other meso-level institutions, stemming from university TTOs, patent agencies, and private and public collections, might also affect material access and exchange. Given that our data do not allow us to explore these institutions, we suggest that future research studies could collect observational data that better capture the details of national policies and meso-level institutions.

Despite these limitations, our theoretical framework and findings provide several important implications for policy and suggestions for future research. Our paper advances theory by developing

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Table 4. Model estimation (Tobit).

	Receipt Likelihood			Stoppage Likelihood			Delay Likelihood		
	Tobit Model			Tobit Model			Tobit Model		
	Estimate	Std. error		Estimate	Std. error		Estimate	Std. error	
Intercept 1	1.92	0.57	***	2.76	0.67	***	3.89	0.66	***
Intercept 2	−0.21	0.08	**	−0.04	0.07		−0.05	0.07	
Regulative institutions									
Nagoya Protocol	−0.92	0.28	***	0.73	0.32	*	−0.27	0.31	
National regulation	0.08	0.06		0.08	0.07		0.08	0.06	
Meso-level institutions									
Organizational Oversight	−0.21	0.07	**	0.28	0.08	***	0.22	0.08	**
Regional Proximity	0.30	0.12	*	−0.36	0.14	*	−0.39	0.14	**
Collab. Res. Net.	0.73	0.28	**	−1.09	0.33	***	−0.06	0.31	
Interpersonal networks									
Communication	0.28	0.13	*	−0.10	0.15		−0.23	0.15	
Friendship	0.35	0.27		−0.17	0.31		−0.61	0.31	*
Help With Regulation	0.52	0.37		−0.78	0.46		−0.83	0.41	*
Control variables									
Developing country	0.10	0.17		0.03	0.21		0.51	0.20	**
Junior	0.08	0.17		−0.26	0.21		−0.28	0.19	
Private	−0.11	0.31		0.26	0.35		−0.23	0.34	
Dependency	0.09	0.24		0.63	0.28	*	0.38	0.28	
Plant	0.00	0.15		−0.20	0.18		−0.42	0.18	*
Animal	−0.51	0.31		0.53	0.35		0.63	0.36	
Log-likelihood	−158.71			−185.55			−197.98		
N	160.00			152.00			151.00		

Significance levels: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 5. Model estimation (OLS).

	Receipt Likelihood			Stoppage Likelihood			Delay Likelihood		
	OLS Model			OLS Model			OLS Model		
	Estimate	Std. error		Estimate	Std. error		Estimate	Std. error	
Intercept 1	2.47	0.34	***	2.62	0.47	***	3.53	0.51	***
Regulative institutions									
Nagoya Protocol	−0.41	0.17	*	0.37	0.23		−0.16	0.26	
National Regulation	0.04	0.04		0.06	0.05		0.06	0.05	
Meso-level institutions									
Organizational Oversight	−0.12	0.04	**	0.22	0.06	***	0.16	0.07	*
Regional Proximity	0.17	0.08	*	−0.22	0.10	*	−0.30	0.11	**
Collab. Res. Net.	0.41	0.17	*	−0.74	0.23	**	−0.07	0.26	
Interpersonal networks									
Communication	0.16	0.08		−0.04	0.11		−0.18	0.13	
Friendship	0.16	0.17		−0.14	0.23		−0.46	0.26	
Help With Regulation	0.28	0.23		−0.54	0.33		−0.63	0.35	
Control variables									
Dev country	0.04	0.11		0.04	0.15		0.40	0.17	*
Junior	0.07	0.11		−0.22	0.15		−0.22	0.16	
Private	−0.09	0.19		0.13	0.26		−0.09	0.29	
Dependency	0.03	0.15		0.51	0.21	*	0.24	0.24	
Plant	−0.07	0.10		−0.07	0.13		−0.31	0.15	*
Animal	−0.27	0.19		0.39	0.26		0.55	0.30	
R^2	0.19			0.24			0.23		
Adj. R^2	0.12			0.17			0.15		
N	160.00			152.00			151.00		

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and testing an integrative framework that combines theoretical approaches proposed in previous studies and encompasses the complexity of data access in an international research setting. Most hypotheses were confirmed showing the importance of a multi-level approach to study research constraints in international research settings.

Our study finds support for concerns raised in prior literature (Cock et al. 2010; Neumann et al. 2017; Welch et al. 2013) that international agreements such as the Nagoya Protocol are increasing barriers to access biological materials. We suggest two explanations. First, the Nagoya Protocol might be increasing the complexity of the regulatory environment in which genetic resources are exchanged and thereby creating fundamental barriers to material exchange. Second, lack of awareness and limited competences of scientists to navigate regulations may significantly increase time, effort, and resources required to access material. Future work should examine how resources and familiarity moderate the effect of regulative institutions on access.

Our finding that national, state, and local regulations do not increase barriers might support the second explanation. Namely, scientists have become more knowledgeable about and adept at addressing national regulations, such that material access is not blocked or delayed by these institutions. As awareness and competencies of scientists increase over time, the barriers raised by regulative institutions might disappear. It might also be that there is a wide variation in the types of policies and enforcement mechanisms that are at work at local, state, and national level; future research may want to explore this heterogeneity to further confirm the role of institutions stemming at the country level.

Regarding meso-institutions, our study finds that organizational oversight policies which grant scientists greater autonomy increase access to biological material. We suggest several explanations. Scientists with greater autonomy could be better able to negotiate access and sharing conditions. Strict organizational policies would reduce individual autonomy and increase barriers to exchange, access, and use of biological materials. But there are also competing explanations worthy of future investigation. It might be that scientists who receive more autonomy are more likely to avoid compliance with regulations. Under this scenario, lower oversight from organizations translates into more pernicious behavior and scientists gain access to biological materials without adhering to expectations of fairness and equity. If that is the case, there are high risks of long-term negative repercussions on international scientific collaboration as such behaviors would increase perceptions of favoritism or biased treatment among scientists and governments across institutions and countries. In most cases, meso-level institutions are in place to ensure compliance with regulations, promote behaviors that respect principles of fairness and equitable use and share of biological material, protect innovation, or block transfer of biological material that might raise safety or health concerns, among other goals.

We also show that regional proximity has a positive effect on access to biological materials. The importance of regional collaboration and agreements emerge from our analysis and interviews with scientists at the ILs. Complementarities and synergies across neighboring countries could significantly help to establish collaborative governance mechanisms and promote lower barriers to the exchange of biological materials. Future studies should disentangle mechanisms that facilitate collaboration from individual network factors to better articulate the regional effect.

Finding also show that scientists rely on the friendship ties in their network to reduce delays in obtaining materials, but neither friendship nor instrumental ties affect the likelihood of obtaining materials. These results point to two possible implications. First, interpersonal networks facilitate scientists' timely access to material, but they do not increase chances of obtaining material or remove stoppages. Hence, scientists engaging in international research cannot completely rely on interpersonal networks to gain unobstructed access to biological material. Second, our results corroborate the idea that reciprocity is fundamental in resource exchange. Scientists who collaborate more frequently are more like to help each other and provide access to biological material. Providing material to a close collaborator might mean greater opportunities for publication, development of future research and projects, and access to benefits deriving from the research such as rents earned from innovations.

Our study points to several opportunities for future research. An important yet unexplored area of study is the relationship between institutional constraints and network ties. The cross-sectional nature of our data does not allow us to explore how institutional constraints shape the composition of scientists' network. We expect that greater institutional constraints would affect network structure and composition. Scientists who are subject to greater institutional constraints might explore new collaborations and relationships to reduce the constraints they face. By contrast, as regulation increases and scientists are left with limited autonomy to establish conditions for accessing and exchanging material, strong ties will matter less as there are increasingly fewer risks and costs to absorb. Conditions and requirements will be established by the regulations and will provide guarantees on the outcome of the exchange. Scientists will be more likely to exchange with others who are willing to meet with the formal obligations determined by the institutional constraints rather than making their decision based on trust and expectations of reciprocity. This would be perceived as a positive outcome for some scientists as compliance with institutions could lead to positive outcomes such as protecting traditional knowledge, promoting equitable and fair access, use and benefit sharing, enhancing capacity development, and facilitating new forms of collaboration (Bulletin of the Ecological Society of America 2018; Kamau 2010; van Zonneveld et al. 2018).

We also argue that meso-institutions should receive greater attention in research on biological material exchange and access. Previous studies focus on international regulations (Nijar et al. 2016; van Zonneveld et al. 2018) or bilateral agreements (Yeh et al. 2017), but do not systematically integrate regional and organizational institutions in international settings. For instance, to our knowledge there is no comprehensive analysis of university policies, how they differ, and how such differences affect access, exchange, and use of genetic resources and, ultimately, scientific production. Findings from our research also suggest that regional collaboration and proximity significantly affect access, stoppages, and delays in obtaining material. Scientists do not work independently; they are part of a research system (Hessels et al. 2011) in which groups, networks, and other organizations and institutions significantly shape interactions and processes. To further understand issues of access and exchange, research should explore how different collaboration forms at the regional level facilitate or hinder access to biological material.

Finally, we encourage more research that investigates both costs—such as reduced access to biological material—and benefits of regulative and meso-level institutions. As mentioned above, rationales for regulation include more equitable benefit sharing, protection of traditional knowledge, and reduced biopiracy. To what extent are these being accomplished? Additionally, regulations could result in new forms of collaboration that are more inclusive of developing countries and promote the exchange of reciprocal benefits

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such as research skills, technical capacity, and support, access to equipment and education and visiting opportunities. Provision of such benefits might facilitate access to biological material (Shibayama and Lawson 2018) and simultaneously involve local scientists to develop better practices for international research (van Zonneveld et al. 2018).

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Notes

1. For the full list of countries: https://www.cbd.int/abs/nagoya-Protocol/signatories/ (accessed 31 March 2017).
2. 'Genetic resources' is a broad term that also includes biological material.
3. To our knowledge there is no extensive review of university policies concerning transfer of biological materials, despite wide discussions in the literature. Examples of university policies can be found here: http://www.spo.berkeley.edu/guide/mtaquick.html (UC Berkley) or here: http://psimr.asu.edu/MTA.html (Arizona State University).
4. We excluded from this analysis cases where respondents indicated regions instead of countries (i.e. 'East Africa') or collective actors (i.e. 'Icrisat').
5. For the complete list of countries, see: https://www.cbd.int/abs/nagoya-Protocol/signatories/ (Accessed March 2017). We included only countries who ratified the Protocol and excluded countries who only signed the Protocol. At that point in time, USA did not have signed nor ratified the Protocol.
6. FAO geographical regions can be found here: http://www.fao.org/faostat/en/#definitions
7. http://www.fao.org/faostat/en/#definitions
8. Examples of using Tobit models on theoretically censored Likert scales from survey data include (Bretschneider 1990; Long 1997; Greene 2000). Doubled-censored Tobit models show better results than OLS or single censored model (Greene 2000). Results from OLS estimation can be seen in Table 5. Overall results did not differ significantly from those obtained in the Tobit models; small divergences in significance are to be expected because of the different assumption on the variable distribution (Long 1997).
9. Models have been estimated using the VGAM package (vglm function) in R 3.4.1.

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