# Exclusive Sharing of Genetic Materials in U.S. Agricultural Research:

# Antecedents and Consequences

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# 1. INTRODUCTION

## 1.1. Background

Genetic materials containing functional units of heredity became vital for scientific knowledge production as well as industrial innovation in modern science (Stern 2004; ten Kate 2002). Given the significance of genetic materials in science, various policy measures have been devised to promote sharing of genetic materials and research tools among scientists; they include funding agency policy (e.g., National Institutes of Health) that requires funding awardees to make data and research materials available to peers (Marshall 1998, 1999; NIH 1999), and more collective efforts to establish open databases or gene banks in order to collect, store, and distribute genetic materials as well as associated information for a broader range of stakeholders (Atkinson et al. 2003; Stern 2004). In agriculture and food research, advanced science based on open access to genetic materials and information has been advocated not only for benefit of the scientific community but also for ultimate societal benefits, such as agricultural productivity, food safety and public health (Atkinson et al. 2003; Glenna et al. 2007; Lei, Juneja, and Wright 2009).

Nonetheless, increased restrictions have been placed on access to genetic materials along with the expansion of intellectual property rights (IPR) protections (Campbell et al. 2002; Walsh, Cohen, and Cho 2007), and the development of multi-layered regulations at national and international levels (Black and Kireeva 2010; Santilli 2012).

IPR protections have expanded with national and international patent laws and treaties, such as the International Convention for the Protection of New Varieties of Plants (UPOV), US Plant Patent Law, and the Trade-Related Aspects of Intellectual Property Rights (TRIPS). At the same time, private proprietary institutions have penetrated American public research institutes with a series of legislation and policy initiatives including the 1980 Bayh-Dole Act. The increased restrictions on genetic materials along with the creation of these institutions are reported to hinder scientists' ability to initiate and complete research in a timely manner and cross-validate peers' works, which may ultimately hinder scientific advance (Lei, Juneja, and Wright 2009).

Passage of the Nagoya Protocol (NP, 2010) has revitalized a policy discussion on the limited access to genetic materials in science (Cock et al. 2010; Jinnah and Jungcurt 2009; Koopman 2005; Kursar 2011; Martinez and Biber-Klemm 2010; Oguamanam 2010; Trommetter 2005). The NP, as a protocol to the Convention on Biological Diversity, promises to establish a regulatory regime for the exchange of various biological materials across borders. While in many ways, the NP is designed with national rights and conservation motives in mind, it has also raised questions about potential negative consequences for scientific research and knowledge development (Jinnah and Jungcurt 2009; Martinez and Biber-Klemm 2010). Questions that are often raised about this complex issue include: What factors impede access to genetic resources? Why do some researchers agree not to pass on material? Are regulatory constraints or other factors to blame? Does variation in access to genetic resources affect the production of knowledge and other scientific outputs such as intellectual property? Although the answers to these questions are critical for ongoing policy implementation, they have not been well addressed by the academic or policy communities.

Prior research has identified access issues associated with institutional changes. Scientists are found to encounter increasing substantial barriers in obtaining genetic materials as commercialism and competition increase in a scientific community. Scientists themselves are often found to withhold genetic materials for their own research (Campbell et al. 2002; Walsh, Cho, and Cohen 2005). Nevertheless, previous research provides only a partial perspective. Most of the previous studies (Eisenberg 2006; Rodrigues 2007) associate sharing restrictions with macro-level science institutions (i.e., open science vs. proprietary institutions) while paying little attention to sharing actors and sharing processes. Moreover, previous studies (Blumenthal et al. 2006; Campbell et al. 2002; Walsh, Cohen, and Cho 2007) simply focus on social institutions without considering the interaction between ecological systems and social institutions. Given the broad range of genetic materials used in science, it is important to incorporate geo-ecological components of genetic materials to explain why some materials are more openly exchanged than others.

## 1.2. Scope and Objectives

Acknowledging the need to develop a comprehensive view, this research aims to investigate socio-ecological factors shaping scientists' access to genetic materials. As a way to understand accessibility of genetic materials in science, this research examines exclusive sharing of genetic materials among scientists. Exclusive sharing is defined as a specific situation in which agricultural scientists provide genetic materials to a selected person but do not allow the materials to be shared with a third party.

Various socio-ecological factors are proposed to influence exclusive sharing. Borrowing insights from multiple theories – transaction cost theory, social exchange theory, theory on science institutions, and socio-ecological system theory, this dissertation considers exclusive sharing to be influenced not only by science institutions or research environment but also by the attributes of shared objects (i.e., genetic materials), sharing actors, and sharing process.

Furthermore, this study examines whether exclusive sharing without a third party transfer brings about particular consequences. The consequences of exclusive sharing are primarily examined with a consideration of specific research outcomes, such as publications and intellectual property related outcomes. Therefore, the primary research questions of this dissertation are as follows:

- What socio-ecological factors influence scientists' exclusive sharing of genetic materials?
- What are the consequences of exclusive sharing in terms of research outcomes?

In sum, this dissertation develops a comprehensive view on how researchers' exclusive sharing is shaped and linked to research outcomes of agricultural research. Multiple socio-ecological factors are proposed to influence exclusive sharing in a research project, which, in turn, influences research outcomes of the project.

## 1.3. Research Design

This dissertation employs quantitative methods to understand the antecedents and consequences of researchers' exclusive material-sharing. Structural equation models and probit regression models are used to examine the process through which researchers decide not to transfer the obtained genetic materials to a third party and generate a particular research outcome.

Data come from a 2010 survey of government and university researchers and an identical 2011 survey of company researchers. The sample frames of both surveys include the U.S. national population of researchers who use non-plant genetic resources (i.e., microbes, livestock, aquatics, and insects) for food and agricultural research. In total, 1,435 individuals were invited to complete the 2010 survey (response rate: 44.6%), whereas 1,060 individuals were invited to complete the 2011 survey (response rate: 21.3%). In addition to individual-level data, the surveys collected project-level data from respondents. About 66 percent of respondents who completed either the 2010 survey or the 2011 survey indicated that they had active projects and generated project data. In total, 973 project-level data were collected from 367 respondents.

The unit of analysis is a research project. Research projects serve as an "action arena" (Ostrom 1998) in which individual scientists make a decision on material-sharing and produce a certain research outcome. An investigation on a specific action arena helps understand the direct linkage between material-sharing and research outcomes. Furthermore, the analysis of action arenas – individuals' project-level activities including specific types of material-sharing – are specific enough to uncover not only macro- but also micro-level factors associated with exclusive sharing and research outcomes. Analysis of the project-level data enables the systematic investigation of exclusive sharing by aggregating, comparing and summarizing the quantified data. A project-level analysis in this dissertation can alleviate concerns about the theoretical complexity caused by fragmented frameworks and case study-based studies (Padmanabhan and Jungcurt 2012), while presenting a way to integrate multiple theoretical approaches that essentially account for specific, but comparable, sharing contexts and research outcomes. Therefore, project-level data is used to reveal the sequential process in which exchange patterns of genetic materials are linked with research outcomes.

## 1.4. Significance of the Dissertation

Theoretically, this dissertation makes several contributions to the study of material-sharing and research management by developing a concept of exclusive sharing and a comprehensive socio-ecological framework explaining exclusive sharing. Attention on exclusive sharing would be particularly useful in order to uncover the specific contexts in which individual scientists engage in material-withholding as well as material-sharing and develop confidential collaboration arrangements. This study of exclusive sharing advances our understanding of the micro-level process by which individuals are included and excluded, delineate boundaries of sharing, and distinguish in-groups from out-groups. It also sheds light on the critical moment at which access to genetic materials begins to be blocked from a third-party. This helps understand the specific contexts that promote a transition in the status of genetic materials, from public or common goods available to the public, to private or club goods available only to selected entities.

Socio-ecological components of exclusive sharing identified in this study are particularly meaningful. This is because scientists' sharing of genetic materials is not merely a byproduct of the science production system but is also situated within diverse socio-ecological conditions. An empirical analysis on the linkage between exclusive sharing and research outcomes will provide a valuable lesson in research management.

From a practical point of view, this dissertation, which is based on nation-wide observations, provides a timely assessment of limited access to genetic materials in the field of agriculture and food research. This assessment helps answer several policy questions about the desirable roles of public and private institutions in governing global genetic materials and promoting scientific research on genetic materials. Policy recommendations in this research are relevant to reconsider the on-going development of open-sharing policies and public gene banks. They are also informative enough to adjust the global environmental governance system proposed by the Nagoya Protocol to more closely represent reality.

## 1.5. Structure of the Dissertation

This dissertation is organized in six chapters. Chapter one is an overview of this dissertation. It introduces the background that motivates this research of exclusive sharing, and specifies its scope, objectives, and key research questions. It then explains the research designs employed to answer the key research questions, and elaborates the significance of this study. The outline of this dissertation is also presented in the end of Chapter one.

Chapter two identifies the relevant policy contexts and theoretical foundations of this study. First, divergent understandings of material-sharing in three different policy approaches are introduced and the contingencies of exclusive sharing are uncovered in a discussion of public versus private goods. Then, given the coexistence of collaboration and competition, exclusive sharing is conceptualized as material-sharing among selected entities. Lastly, theoretical insights drawn from science institution theory, socio-ecological system theory, social exchange, and transaction cost theory are integrated to explain the multi-level motivations associated with exclusive sharing.

Based on the theoretical foundations identified in Chapter two, Chapter three develops testable hypotheses and propositions. The antecedents of exclusive sharing include not only the science institutions or research environments but also the socio-ecological attributes of shared objects (i.e., genetic materials), sharing actors, and sharing processes. Exclusive sharing is also hypothesized to influence a specific research outcome (i.e., publications and intellectual property outcomes) in a different way. The end of this section presents a conceptual framework explaining the process through which socio-ecological attributes of multiple sharing components influence scientists' exclusive sharing and affect particular research outcomes.

Chapter four describes the study sample employed: U.S. agricultural research that uses non-plant genetic materials. It elaborates data collection processes based on two national web surveys and additional archival search. The measures and methods used in empirical analyses are also specified. In addition, the chapter discusses potential item-nonresponses given the presence of missing items in the survey data and elaborates multiple imputation methods used for missing items. The end of the chapter presents a brief summary of descriptive statistics and a description of the empirical model used in this study.

Chapter five reports the findings of the empirical analyses. First, univariate and bivariate statistics are presented, followed by multivariate analyses based on probit regression models. Then, structural model estimates are documented. Chapter six summarizes main arguments of this dissertation and presents both theoretical and practical implications. It also describes the study’s limitations and suggestions for future research.

# 2. THEORETICAL FOUNDATIONS

This chapter introduces various policy contexts in which sharing of genetic materials has been discussed in recent decades. Furthermore, it introduces overarching theoretical foundations that integrate fragmented policy discussions on material-sharing. Theories overviewed in this chapter include: research on the public-private distinction, club goods theory, economic institutional theory, socio-ecological system theory, and social exchange theory. Based on literature review, this chapter conceptualizes exclusive sharing as a type of bilateral material-sharing which embraces research collaboration versus competition, and private goods versus public goods. It also uncovers multi-level theoretical frameworks that could be applied to understanding of exclusive sharing.

## 2.1. Multiple Streams of Policy Development

Genetic resources are broadly defined as biological materials which contain functional units of heredity (ten Kate 2002). In the agriculture and food sectors, genetic materials range from seeds, eggs and semen to whole organisms. Parts of organisms, such as cells and tissues, plasmids, virus, and DNAs, are commonly used and exchanged by researchers. Along with organisms, genetic information on the molecular, physiological and structural attributes of organisms is also shared (Stern 2004, 11).

A very long time ago, genetic materials were freely exchanged among individuals. In the 19$^{th}$ century and even in the early 20$^{th}$ century, genetic materials were freely available to farmers, breeders, and scientists (Louwaars et al. 2006). During the Progressive Era, the US Patent Office and the US Department of Agriculture (USDA) provided farmers with free seed packets and encouraged them to adapt varieties to local ecological conditions through experimentation in breeding (Dutfield 2008, 28). Later, the USDA supported scientists' free access to plant genetic materials while funding public research on hybrid seeds (Dutfield 2008).

At the global level, open access to genetic materials beyond national jurisdictions has been supported historically as well. Based on the "common heritage" principle (de Jonge 2011; Louwaars et al.

2006, 56), genetic resources on the Earth have been described as the heritage of mankind so that anyone can use them for the common interests of human beings. This "common heritage" tradition is still found in international policies. For example, the United Nations Convention on the Law of the Sea (UNCLOS) grants free access to marine resources in Areas Beyond National Jurisdictions (ABNJs), although marine resources in Exclusive Economic Zones (EEZs) are not freely accessible. Considering that ABNJ's account for approximately sixty percent of the sea (Arnaud-Haond, Arrieta, and Duarte 2011), it can be said that the principle of common heritage is still widely recognized.

Nonetheless, access to genetic materials has been increasingly restricted due to multiple streams of policy development. The formulated policies associated with genetic materials cover a broad range of issues, such as intellectual property rights, bio-safety, social equity, and environmental conservation. Currently, genetic materials are governed by a web of multi-layered policies. The following section categorizes a wide array of policies regulating genetic materials into three groups: 1) policy incentivizing intellectual property rights over genetic materials, 2) policy advocating sovereign rights and national interests over the materials, and 3) policy promoting open access to genetic materials.

#### 2.1.1. Policy on Intellectual Property Rights

Drahos (1996) notes that intellectual property rights is "a twentieth-century generic term" which had not previously existed but emerged along with industrialization (Drahos 1996, 14). Modern mass manufacturing enabled the rapid and easy copying of others' original works so that the rights of inventors were frequently infringed on. In response, trade associations and international organizations developed a legal framework that could protect the intellectual property rights of inventors.

In the agriculture and food sectors, genetic materials used to be owned, produced, and reproduced by farmers and small-scale breeders without any legal specification of intellectual property rights over the materials (Dutfield 2008; Louwaars et al. 2006). In traditional agriculture, farmers played a significant role in selecting seeds and varieties based on their knowledge and experience of local conditions. However, since the late 19$^{th}$ century, the breeding industry has become independent from the farming profession. Breeders now specialize in discovering a profitable variety based on their expertise and experience crossing and selecting varieties (Dutfield 2008). In 1890, approximately 600 commercial firms were formed for commercial seed production. They have since developed into modern multi-national companies, such as Monsanto, Syngenta, Dupont and Delta & Pine Land. These seed companies also formed an industry association, the American Seed Trade Association (ASTA) (Dutfield 2008). The ASTA began to advocate for breeders' intellectual property rights on seed selection and criticized the US government's free seed packet program in the early 20th century.[1]

In the US, protection of intellectual property rights over genetic materials, mostly ornamental plants, began with the Plant Patents Act in 1930 (Barton 1982). Plant patents were only granted for species of vegetative and asexual propagation because sexual reproduction was not considered to engender identifiable, uniform and stable progenies that could be patented (Santilli 2012, 85). In 1952, intellectual property rights over genetic materials were expanded with the Patent Act. The Act introduced "utility patents" to agricultural inventions (e.g., farming machinery, and agrochemicals) and later enabled patents for biotechnological inventions and genetically modified organisms. In 1970, the Plant Variety Protection Act was established for patenting sexually reproducing species. The Plant Variety Protection Act (1970) and its amendment (1994) further expanded the scope of new plant varieties that can be patented (Santilli 2012, 86; Williams 1984).[2]

Intellectual property-related activities of genetic materials have further intensified since the 1980s. The Bayh-Dole Act (1980) created a new path for university researchers to patent their inventions. The Act directly motivated universities to pursue intellectual property rights on biomedical inventions; at that time, the growth of the biopharmaceutical market was largely foreseen due to advances in molecular biology research (Eisenberg 2006; Rai and Eisenberg 2003). At the same time, the US Supreme Court

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[1] Nonetheless, the government continued providing seed packets to farmers at no cost until the first World War (Dutfield 2008).

[2] Presently, there are at least three national acts concerning intellectual property on plant genetic materials. They often overlap with each other, which at times causes legal disputes since one plant variety can be covered by multiple patents that were granted to different holders (Santilli 2012).

decision in the case of *Diamond* vs. *Chakrabarty* promoted a new development in biotechnology (Barton 1982; Demaine and Aaron 2003). It granted patent rights to living, man-made microorganisms modified by genetic engineering, which led to rapid growth of the bio-industry.[3]

At the international level, intellectual property rights over plant genetic materials, mostly commercial crops, began to be protected by the International Union for the Protection of New Varieties of Plants (UPOV). The UPOV was first established in 1961, and later modified in 1978 and 1991; the US joined the Union in 1981. The UPOV explicitly declared the rights of breeders who discovered plant varieties which were "new, distinct and stable and uniform" (UPOV 2012). The UPOV was one of the earliest efforts to establish a legal framework for intellectual property rights over biological materials. UPOV members also played a significant role in advancing the World Intellectual Property Organization (WIPO), and even the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement (Dutfield 2008; Santilli 2012).

However, the original UPOV was cautiously designed to avoid restricting access to genetic materials. Under the provision of "breeders' exemption" or "research exemption" in the UPOV, breeders were still allowed access to most of the protected plant varieties; they could use the protected plant varieties for their new inventions without authorization from the original breeder, although they were not allowed to reproduce exactly the same plant variety for commercial purpose (Dutfield 2008; Medaglia 2010; Srinivasan 2010). Moreover, farmers and individual researchers were still able to get access to the protected plant varieties because the UPOV did not include any explicit rules on the non-commercial use of plant varieties (Santilli 2012, 80); farmers could save seeds for their own use and reuse the seeds in future harvests, even though they were not allowed to sell the seeds to others. Therefore, it can be said that the original UPOV recognizes intellectual property rights over genetic materials but also embraces breeders' exemptions and farmers' rights. Later, the revision of the UPOV in 1991 reduced breeders'

[3] Since the case of *Diamond vs. Chakrabarty*, several court decisions have approved the patentability of biological materials (Coriat and Orsi 2002). In every case, a key debate arose on the issue, whether the materials are man-made inventions or naturally occurring traits. The recent supreme court decision that ruled out the patent claims of the Myriad Genetics on the BRCA1 and BRCA2 genes (Marshall 2013) revitalized the controversy over patentability of living organisms in the US.

exemptions and restricted farmers' rights, while granting more exclusive rights for breeders (Santilli 2012).

At the same time, intellectual property rights over genetic materials were integrated with international trade policies and became universal across countries. The GATT Uruguay Round trade negotiation (1986) attempted to incorporate intellectual property rights as a subject of international trade and created a universal rule on intellectual property rights over tradable goods including biological materials (Roffe 2008; Santilli 2012). The Uruguay Round facilitated general discussion on patentability at the international level (Roffe 2008). Moreover, the Uruguay Round expanded the scope of trade from manufacturing to agriculture and food (Roffe 2008). Hence, the Uruguay Round served as an international policy arena for discussing intellectual property rights over biological materials relevant to agriculture and food that are not limited to plants or crops.

After several years of negotiation, intellectual property rights over biological materials were fully incorporated into the World Trade Organization (WTO). The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), a part of the Marrakesh Final Act establishing the WTO in 1994, entered into effect in 1995.[4] The TRIPS Agreement challenges local practices and sets up the principle of minimum standards for intellectual property rights protection (Roffe 2008; Santilli 2012). Before the TRIPS agreement, IPRs were mostly protected by the local policies of each nation. Even among the member countries of the Paris Convention for the Protection of Industrial Property (1883, a previous incarnation of the World Intellectual Property Organization, WIPO), a patent sought in one country could be revoked in another country depending on each nation's interpretation of patentability and local exploitation of the invention. In particular, the agriculture and pharmaceutical sectors were often excluded from global sanctions and protected by each individual nation's policies on food security and public health before the TRIPS came into force (Roffe 2008; Santilli 2012). For example, half of the known

[4] The TRIPS Agreement is now in effect in 159 WTO member countries (WTO 2013). The member countries include most developed countries and BRICS (Brazil, Russia, India, China and South Africa). Each member country has developed measures to enforce intellectual property rights over genetic materials in accordance with the TRIPS Agreement (Santilli 2012) .

national patent laws excluded pharmaceutical products from intellectual property protection, while one third of the laws excluded inventions on food products. In an extreme case, Brazilian patent law excluded the pharmaceutical, agro-chemical and food product sectors from patentability (Roffe 2008, 48). However, every member country is now obliged to protect intellectual property rights over most tradable goods including pharmaceuticals, agro-chemicals, and food products under the TRIPS Agreement. Therefore, the TRIPS is expected to make a significant impact on these sectors in particular.

In addition, bilateral or multi-lateral free trade agreements (FTAs) among nations further articulate parties' obligations to enforce intellectual property rights. For example, regional free trade agreements between the US and Central American countries (e.g., Costa Rica, El Salvador, and Nicaragua) imposed obligations on these countries to adopt the 1991 UPOV Convention. The FTA between the US and Morocco requires the parties to have stronger obligations to grant patents for inventions using animals and plants (Roffe 2008). As intellectual property protection measures are incorporated into international trade agreements, it has become challenging for individual nations to devise counter-measures against IPR protections.

Undoubtedly, IPRs over genetic materials have become more prevalent. It is common to find legal claims associated with IPRs over biological inventions. Intensified IPRs are one of the most commonly cited policy changes that have influenced access to genetic materials (Ghijsen 2009; Lalitha 2004; Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007). Several prior studies (Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007) identify that scientists' access to genetic materials has been restricted along with the development of IPRs.

### 2.1.2. Policy on Sovereign Rights and National Regulations

Sovereign rights and national regulations are considered another force that has influenced access to genetic materials (Santilli 2012, 113). A sovereign right refers to each nation's legal right over its biological materials. It is legitimized to be for public benefits of the nation, not the private interests of individuals. Yet, it is primarily concerned with national jurisdiction and national interest instead of global ownership or global benefits. The Convention on Biological Diversity (CBD) is a typical example of an international institution that promotes sovereign rights over biological resources (Koopman 2005; Merson 2000; Santilli 2012). In the CBD, biological resources are essentially considered as national assets. Article 15 of the CBD explicitly states that the country of origin may determine conditions for access to its resources. Although the CBD aims to pursue global-wide conservation and sustainable use of biological resources, the goals are seen to be achieved by sovereign rights over biological resources.

The principle of sovereign rights in the CBD originated from a critical review of inappropriate bio-prospecting or bio-piracy in which international private entities made a profit off of developing countries' biological materials without permission or compensation to the material holders (Merson 2000). Bio-piracy is believed to cause a significant loss of biological diversity not only because it favors irresponsible overexploitation of biological resources but also because it weakens the research and development capacity of resource-holder countries (de Jonge 2011; Merson 2000; Overwalle 2005). Therefore, the CBD has attempted to ensure access to genetic materials with proper permission from resource-holder countries and establish an equitable mechanism through which resource-users return benefits from the use of biological resources to resource-holder countries. Resource-users are increasingly requested to obtain prior informed consent (PIC) from resource-holder countries and/or local communities before getting access to biological resources abroad. The CBD further recommends the use of mutually agreed terms (MATs) which clearly state the terms of access and use of biological resources including provisions for benefit-sharing (UN CBD 2011). The Nagoya Protocol adopted in 2010 by the CBD member countries is a result of ceaseless efforts over the course of a decade to push the negotiations between resource-holder and resource-user countries (Glowka and Normand 2010; Hogue 2010). The protocol further specifies conditions for access and benefit-sharing (ABS) in which resource users are obliged to provide monetary or non-monetary compensation to resource-holder countries. The principle of sovereign rights was reconfirmed in the Nagoya Protocol; sovereign control of the "access-determination process" was believed to ensure fair and equitable benefit-sharing (Glowka and Normand 2010, 23).

Moreover, each nation has developed its own regulations and policies restricting the entry of biological hazards for health and safety reasons (Black and Kireeva 2010). For instance, the United Kingdom has developed a policy to safeguard against alien species that have been intentionally or unintentionally introduced based on a risk assessment of their impact on the environment (Baker et al. 2007). International policies, such as those established by the International Plant Protection Convention (IPPC) and the World Organization for Animal Health (OIE), also created a border barrier by restricting the trans-national movement of pests, disease organisms, pathogens, and invasive species (Black and Kireeva 2010). Even in the free international trade system under the GATT and later the WTO, the Application of Sanitary and Phyto-sanitary Measures set forth conditions in which a nation can investigate and block the entry of biological materials in order to prevent catastrophic diseases and harm to its national population and environments (Black and Kireeva 2010). These regulations at the national and international levels have also created barriers in material-sharing across nations.

### 2.1.3. Policy on Open Access to Genetic Resources

On the other hand, there are other policy perspectives that see genetic materials as communal assets and promote open access to genetic materials. Policies and programs at multiple levels have been established to create and support certain types of communities that allow its members to freely use and exchange genetic materials. Researchers have sought to consistently develop small scale individual collections based on their research needs, whereas multiple public initiatives and research consortia have facilitated the expansion of individual collections and the establishment of publicly accessible gene banks or bio-banks.

On a relatively small scale, individual efforts have been made to establish publicly available bio-banks and open databases on genetic materials. In the field of microbiology, culture collections – housed in an individual lab or an organization – served as a primary repository of genetic materials in early years. The first culture collection was established by the Frantisek Kral at the German University of Prague in 1890 (Stern 2004; Uruburu 2003). After Kral’s death, the collection was transferred to the State Serum

Institute (SSI) in Vienna. Later, a part of the collection was taken to Loyola University in Chicago by the director of SSI, while the rest of the collection was destroyed during World War II (Uruburu 2003). In the US, the Society of American Bacteriologists (now the American Society for Microbiology) first established a culture collection in 1899. It expanded to join the collection at the Museum of Natural History in 1911 under the vision of creating "a museum of living bacteria" (Clark and Geary 1974). Individual culture collections were primary sources of the Agriculture Research Services (ARS) culture collection as well. Dr. Charles Thom acquired several hundred mold cultures while working at the Connecticut Experiment Station and brought his collection, later known as the Thom and Church collection, to Washington, D.C. (USDA ARS). In 1940, he deposited about 2000 cultures to the Northern Regional Research Laboratory (now the National Center for Agricultural Utilization Research in Peoria, IL). Other individual collections, such as Dr. Wickerham's collection of yeasts, also contributed to an expansion of the ARS culture collection (USDA ARS). A tradition of individual endowment was built upon open science norms legitimizing open sharing of research materials among peers; materials deposited in culture collections were readily available for scientific verification (Uruburu 2003).

Since the early 20th century, the idea of maintaining a more centralized repository began to emerge. The American Type Culture Collection (ACCC) was a typical example of a centralized repository established by a consortium of scientific societies (Clark and Geary 1974). It grew rapidly and became the premier culture collection with over 2000 strains in 1937 (Stern 2004, 17). The ACCC further expanded a collection of viruses with additional financial support from the National Science Foundation (NSF) and the National Institutes of Health (NIH) in the 1950s and 1960s. The Budapest Treaty on the International Recognition of the Deposit of Microorganisms for the Purposes of Patent Procedure (i.e. Budapest Treaty) further facilitated expansion of the ACCC. The Budapest Treaty mandates inventors deposit biological materials in a publicly available international culture collection before they obtain a patent on the materials. Since the enactment of the Budapest Treaty, the ACCC has served as one of the international patent depositories. Along with the development of life science and biotechnology industry, culture collections have rapidly grown in terms of the number and kinds of materials conserved (Stern 2004).

Modernized, large scale collections are often called “bio-banks”. Bio-banks feature a facility that incorporates genetic information with genetic materials (Stern 2004). For instance, the ACCC maintains large and varied collections of biological materials (e.g., cell lines, microorganisms, recombinant DNA material, media and reagents) on which information is systematically documented so researchers can easily gain access to valid materials (Stern 2004, 10). At the global level, the World Federation of Culture Collections (WFCC) provides a scientific community with standardized information on strains that are maintained in hundreds of culture collections around the world (Herdt 2012). The Agricultural Research Service of the US Department of Agriculture has also developed an database, namely the GRIN (Genetic Resources Information Network), that manages four major germplasm collections: the National Plant Germplasm System, the National Animal Germplasm System, the National Microbial Germplasm Program, and the National Invertebrate Germplasm Program (USDA ARS; Volk and Richards 2008). These large collections equipped with data management systems serve as a “library of life” (Benford 1992) providing both genetic information as well as genetic materials to the public.

The development of gene banks or bio-banks is aligned with multiple public initiatives promoting sharing of research materials (Hilgartner 1995). Most of the initiatives began with the assumption that knowledge is more or less a common good co-produced by a scientific community (Stern 2004; Uruburu 2003). Therefore, it is legitimate to promote sharing of research materials, including genetic materials used for research, which will help peers discuss prior research and further verify facts (Rodriguez 2005). Fatal errors caused by misidentification and contamination of genetic materials used in research (e.g., the HeLa cell contamination) further promoted the development of policies mandating disclosure of research raw materials as well as research outputs (Stern 2004, 12-13).[5] Since the 1990s, public agencies, such as

[5] Stern (2004) briefly summarizes a story of HeLa cell introduced by Gold (1986). HeLa cell was a human tumor cell that had been successfully cultured by the Gey Lab in 1951. Since then, researchers around the world began to enthusiastically use the culture of HeLa cell in research. However, during the cultivation, some tissue cultures were often mislabeled or cross-contaminated. The negative consequence of this poor practice was not known until the late

the National Institutes of Health and the National Academy of Science, have requested that their funding awardees disclose research raw materials as well as research results to the public - such as publicly available bio-banks or online database - so that their peers can validate their research (Marshall 1998, 1999; NIH 1999). Similarly, journals published by major publishers and researcher associations such as Nature, Science, Aquatic Microbial Ecology, and Plant Cell, began to adopt an open data policy requesting authors to deposit raw biological materials and data at an assigned bio-bank upon their publication (McCain 1995).

Another movement promoting sharing of genetic materials is in agricultural policy advocating the public function of genetic materials relevant to agriculture and food (Glenna et al. 2007; Lei, Juneja, and Wright 2009; Rajan and Divakaran 2009). Biological open source has been promoted via Biological Innovation for Open Society (BiOS) (Lei, Juneja, and Wright 2009). Sharing of research materials and tools in agricultural science has been also promoted by the Public Intellectual Property Rights for Agriculture (PIPRA) (Atkinson et al. 2003). Acknowledging the significance of genetic materials in food security and agricultural sustainability, the US Department of Agriculture has promoted making genetic materials conserved in public gene banks broadly available to farmers, breeders and researchers (Atkinson et al. 2003). At the global level, a similar approach promoting a common goal to preserve and share genetic materials is found in the Consultative Group on International Agricultural Research (CGIAR). CGIAR hosts gene banks which aim to relieve suffering from hunger in developing countries (CGRFA 2010; Herdt 2012). In 1971, four centers established in Mexico, Colombia, Philippines, and Nigeria joined the CGIAR, which later became an intergovernmental organization with 64 member countries and 16 regional gene banks (CGIAR 2013). The CGIAR gene banks hold approximately 750,000 accessions of major crops – about 10% of all the world-wide crop accessions currently maintained (CGRFA 2010, 55) – and make them available to farmers, breeders and researchers throughout the world.

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1960s when Gartler's research in 1968 found that 24 out of 36 "distinct" human cell line in the ACCC were contaminated Hela Cell. This accident alarmed a scientific community and called for the need to disclose raw materials used for research in addition to research findings for scientific verification.

On the largest scale, the International Treaty on Plant Genetic Resources for Food and Agriculture (IT PGRFA) intended to create a global community which shares plant genetic resources without additional requirements (Halewood and Nnadozie 2008; Santilli 2012, 118). The main project supported by the IT PGRFA seeks to develop a "multi-lateral system of access and benefit sharing (MLS)" where any member country has access to other members' plant genetic resources for free or at a low cost.[6] If member countries wish to withhold genetic materials for their own research, breeding and other types of development, they are required to deposit a certain percentage of the profits gained from the use of genetic materials to the conservation fund managed by the treaty community (Halewood and Nnadozie 2008, 81). The treaty was established by the Food and Agriculture Organization of the United Nations (FAO) in 2001 and was enacted in 2004.

#### 2.1.4. Summary

In summary, multiple policies have developed over time in order to govern the use and exchange of genetic materials at local, national and international levels. They can be categorized into three approaches: policy on intellectual property rights over genetic materials, policy on sovereignty rights and national interests, and policy on open access to genetic materials. On the one hand, the first two approaches counteract the traditional "common heritage" principle while creating barriers which limit free access to genetic materials. On the other hand, the third approach revisits the "common heritage" principle and attempts to build a community that freely shares genetic materials, although motivations for sharing vary across individual policies and programs.

Overall, contemporary policies on genetic materials contradict each other as far as access to genetic materials is concerned. More fundamentally, each policy presents its own way of understanding genetic materials. The approach advocating intellectual property rights views genetic materials as private goods, whereas the other approaches consider them collective goods, such as national assets or communal

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[6] For individual users in non-member countries, the treaty requires that they sign the standard material transfer agreement (SMTA) in order to obtain genetic materials from member countries. The SMTA is a bilateral contract between a material provider and a recipient that can be enforced within the national jurisdictions of each party (Santilli 2012, 134).

assets. Nonetheless, none of these approaches fully reflect reality. In an international transfer under the CBD, genetic materials, as a national asset, are monitored and negotiated by national governments. It is still possible that individuals or local communities claim their rights over the materials instead of government agencies within the nation when the materials have been conserved and managed by individuals or local communities (Santilli 2012). At the same time, genetic materials can also be treated as tradable private goods under the TRIPS.

The multiple policies applied to genetic materials in diverse contexts reflect the multi-faceted nature of the materials. Genetic materials are sometimes understood as private goods and sometimes seen as conservation targets or research inputs that can be used for public purposes. Some materials are shared only among a certain network of researchers, or collectively governed by a local community. Other materials are publicly available in public gene banks. Nonetheless, policy discussion often oversimplifies social contexts in which genetic materials are used and exchanged. The next section is built on an acknowledgement that access to genetic materials is contingent on social contexts; materials can be readily available to a certain group while not accessible to others depending on social contexts.

## 2.2. Theoretical foundations

If accessibility and availability of genetic materials change case by case, would it be possible to find any commonality among individual cases? How much can we say about the underlying mechanisms and causal relationships which shape access to genetic materials? Even though these questions were critical in devising relevant policy measures, they are not well addressed in policy discussions. Legal definitions, such as sovereignty rights or breeders' rights, are not informative enough to draw a general understanding about access to genetic materials. Legal or technical definitions for members, donors, holders and users provided by individual programs are much more fragmented. There is much confusion in the discussion on public versus private goods given the different assumptions made by different policy groups (Falcon and Fowler 2002; Halewood and Nnadozie 2008). The quest for generalizable knowledge cannot be achieved without theory.

This section first clarifies definitions and criteria of key terminologies based on literature on public, private, common and club goods. Then, it proposes a public-private continuum of goods which better explains the varied accessibility of genetic materials. As a way to understand accessibility of genetic materials in science, this dissertation particularly focuses on exclusive sharing in which genetic materials are shared among selected entities but not with a third party. Exclusive sharing is conceptualized with knowledge that material-sharing and material-withholding coexist. Four major theoretical approaches are introduced for explaining underlying mechanisms of exclusive sharing.

### 2.2.1. Genetic Materials as Public versus Private Goods

A discussion of whether genetic materials are public or private goods needs to start with a clear understanding of what public and private mean. Neo-classical economics distinguish private goods from public goods as a function of the market (Rhoads 1985). Goods that have price systems are exchanged in a market are private, whereas goods outside the market are public. This approach has been highly criticized by resource economists because natural resources that are not well incorporated into market systems are simply considered public goods (i.e., the externality of a market) (Goodstein 2011; Kolstad 2000). Buchanan (1965) summarizes the argument of neo-classical economics by defining private goods as those owned and consumed by individuals (Buchanan 1965, 2), and public goods as those owned and consumed by a society as a whole (Buchanan 1965, 3).

Nonetheless, Buchanan (1965) points out that most resources fall into a category between private and public goods. People often engage in cooperative and collective sharing, thus forming formal and informal clubs. The shared resources are accessible only for club members but not for non-members. In this sense, club goods are neither public nor private; they are more likely “localized public goods” (Sterbenz and Sandler 1992).

Buchanan (1965) presents a general theory of “club goods” acknowledging a continuum of goods, ranging from the purely private to the purely public. The theory of club goods is useful (Adams and McCormick 1987) in understanding an existing variation in access to genetic materials. It suggests that exclusion costs of goods can motivate individuals to share or not to share their resources with others (Sandler and Tschirhart 1997); individuals may keep goods as private, share them with a certain network of people, or make them available to the public depending on the expected exclusion costs.

In a different vein, resource economics suggests that rivalry of goods may matter (Adams and McCormick 1987; Kolstad 2000; Ostrom 1990). Rivalry refers to the degree to which one's use of a good diminishes the amount of the good that is available for others (Kolstad 2000, 81). In reality, there is competition in consumption. This is because resources or resource suppliers are not always abundant enough to meet consumers' demands or users' needs. Acknowledging competition among consumers or users, resource economists further distinguish common goods from public goods (Kolstad 2000; Ostrom 1990), though both of them are considered to be non-exclusive. Common goods refer to rivalrous but non-exclusive goods, whereas public goods refers to non-rivalrous and non-exclusive goods such as air, sunlight, tidal waves, and other types of renewable energy. Local fishery, forestry, and irrigation systems in developing countries are typical examples of common goods examined in prior studies (Cardenas 2004; Dietz, Ostrom, and Stern 2003; Heikkila, Schlager, and Davis 2011; Ostrom 1990).

Access to common goods is not always secured despite being open to the public. Access may be restricted if common goods have been overused or overexploited by others. Hence, much of the discussion of common goods in prior literature has been devoted to how to use common goods sustainably without overexploitation, how to design institutions suitable for sustainable use, and how to empower user communities for sustainable use (Dasgupta and Heal 1979; Heikkila, Schlager, and Davis 2011; Ostrom 1990). Similar discussions are also documented in policy studies on genetic materials (Dedeurwaerdere 2010; Falcon and Fowler 2002).

Overall, alternative approaches to neo-classical economics (Adams and McCormick 1987; Buchanan 1965; Ostrom 1990; Padmanabhan and Jungcurt 2012; Polski 2005) show that a distinction between public and private goods is not always obvious. Institutional settings beyond the market affect the exchange and use of resources; resources are often treated as quasi-public or quasi-private goods which are neither purely public nor purely private. In fact, the evolution of a market covers a wide range of goods; these include goods that anyone can use, those that only selected group members can use, and others that belong to a private entity (Buchanan 1965; Kolstad 2000).

Acknowledging a wide variation in accessibility and availability of goods used in a society, this dissertation presents a public-private continuum (Figure 1). This public-private continuum challenges an idea of the public-private dichotomy and succinctly summarizes a couple of emerging frameworks on a public-private continuum (Padmanabhan and Jungcurt 2012; Polski 2005).

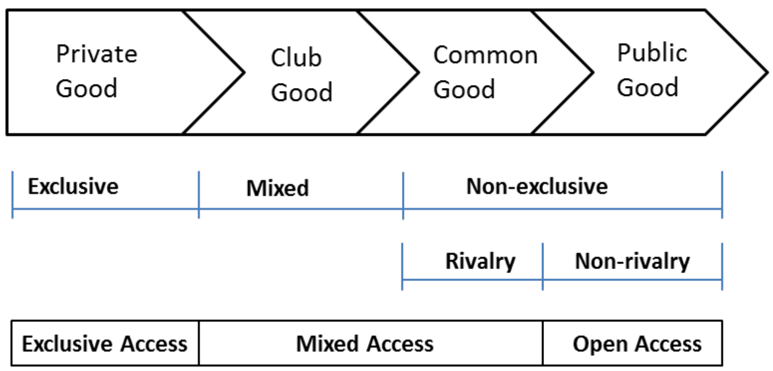


Figure 1. Private, Club, and Public Goods as a Continuum

The public-private continuum implies that accessibility of genetic materials can change with the change in the socio-ecological contexts of use, storage and exchange and these changes coevolve over time (Padmanabhan and Jungcurt 2012; Polski 2005). Previously scarce seeds can become publicly available due to a stable quality and rapid speed of self-reproduction (Padmanabhan and Jungcurt 2012). At the same time, crop varieties that had been publicly available up to the early 19$^{th}$ century since become club goods for plant breeders; along with the development of intellectual property rights, only plant breeders are allowed access to certain varieties for research purposes while those who want to use the varieties for commercial purpose need to purchase (Dutfield 2008). This continuum with gray areas between public and private goods is particularly relevant to genetic materials used in agricultural and food research. This is because markets for genetic materials in agricultural research are still emerging (Padmanabhan and Jungcurt 2012) and research materials are commonly shared via peer-to-peer networks in an informal manner (Bouty 2000; McCain 1991; Welch, Shin, and Long 2013).

Focusing on genetic materials used in science, Polski (2005) articulates that access to genetic materials can change with knowledge-production process. Before being used in research, genetic materials can be public goods, common goods, or private goods. However, once materials begin to be used and transformed for a specific research purpose, the materials become club goods that are only shared among research team members. Later, they may become private goods when patented, licensed and commercialized. The identified parts of genetic materials may again become public goods when deposited in public gene banks or bio-banks upon publication or once a temporary patent protection has expired. In reality, the transition from raw materials to valuable research and commercial assets, and to public knowledge or inventions might not be a linear process as proposed by Polski (2005), given the uncertainty in scientific discovery, research group dynamics and institutional constraints. Nonetheless, the public-private continuum clearly suggests that the public or private nature of genetic materials is not a given but is, instead, socially constructed.

The interplay between genetic materials and social institutions shapes access to the materials, and the public or private nature of the materials (Padmanabhan and Jungcurt 2012; Polski 2005). Therefore, it is essential to understand the socio-ecological mechanisms that influence access to genetic materials. In this regard, this dissertation focuses on the process through which genetic materials are shared or withheld by agricultural researchers. This study rejects a simple assumption that genetic materials from public gene banks are all public goods whereas materials from a private company serve only for selected entities. It also rejects a normative assumption that all the materials from nature are public goods or common goods. This dissertation aims to uncover detailed socio-ecological contexts that shape access to genetic materials and, in turn, influence research outcomes in agricultural research. As one of the critical moments in access to genetic materials, this dissertation focuses on exclusive sharing in which selective entities share genetic materials with each other but do not share the materials with a third party. Based on literature review, the following section defines exclusive sharing and presents theoretical frameworks relevant to exclusive sharing in science.

### 2.2.2. Exclusive Sharing of Genetic Materials in Science

#### (1) Genetic Materials in Science

Genetic materials are one of the important research inputs in the life sciences (ten Kate 2002). They include any material of plant, animal, microbial or other origin containing functional units of heredity of actual or potential value (CBD 1992). Several studies emphasize the significance of genetic materials as research inputs in modern science (Campbell et al. 2002; Hilgartner and Brandt-Rauf 1994; Shibayama and Baba 2011; Walsh, Cohen, and Cho 2007). Some scholars consider genetic materials as a type of "data" because the materials often carry valuable information (Brandt-Rauf 2003; Hilgartner and Brandt-Rauf 1994). Other scholars consider genetic materials as a form of "research tools" that are prepared in early-stage experiments and help further research and development (Ramirez 2004; Shibayama and Baba 2011). Despite the difference in terminology, genetic materials are considered to be vital inputs for research and development (Brandt-Rauf 2003).

Scientists obtain genetic materials from entities outside their organizations, such as public and private gene banks, university and government labs, private facilities and farms located within or outside their nations. Genetic materials obtained from other organizations are mostly in the form of bio-samples or specimens that have been extracted from natural environments and stored in stable *ex-situ* conservation facilities. Scientists also obtain materials from nature or *in-situ* conservation sites that have evolved in specific ecological landscapes. Previous studies indicate that agricultural scientists receive research materials from others about twice a year and biomedical scientists request materials from others more than three times a year (Lei, Juneja, and Wright 2009; Shibayama and Baba 2011). Scientists share even intermediary research tools (e.g., reagents, cell lines, and model organisms) in order to inform others about their current work, prevent duplicate works, increase their visibility in the field, and reinforce their lead in the field. This occurs even if substantial labor, time and expertise have been invested to develop the research tools (Shibayama and Baba 2011; Walsh, Cohen, and Cho 2007).

**(2) Exclusive Sharing of Genetic Materials**

Sharing of genetic materials among scientists has been studied from various approaches. Shibayama and Baba (2011) examine material-sharing as a form of academic cooperation through which researchers provide others with research materials. Walsh et al. (2007) distinguish material-sharing from knowledge sharing and show that material-sharing can be more exclusive than knowledge-sharing in biomedicine research. Haeussler and her colleagues (2009) differentiate "specific sharing" from "general sharing"; specific sharing refers to a bilateral transfer in which a scientist shares her data or materials with another, whereas general sharing is defined as an open disclosure of research materials to the public or the entire research community (e.g., through conference presentations or open databases).

One interesting point identified in these previous studies is the coexistence of multiple motivations involved in material-sharing (Haeussler et al. 2009; Hilgartner and Brandt-Rauf 1994; Hull 1985; von Hippel 1987). Material-sharing is understood to be both a means of competition and a means of cooperation.

In science, it is commonly reported that competition and cooperation coexist (Hagstrom 1974; Oliver 2004; Strevens 2003; von Hippel 1987). On the one hand, scientific production has been considered as a collective effort governed by a whole scientific community; open sharing of research materials has been considered as a critical part for cross-validation and scientific advance (Marshall 1998; Merton 1957; Polanyi 1962). On the other hand, individual scientists are considered as an individual enterprise seeking a new scientific discovery while competing with each other (Merton 1957; Polanyi 1962). Open competition has been promoted to enhance the quality of research, reduce duplicate works, and allocate scientific efforts among important problems in an efficient way (Merton 1957; Polanyi 1962). Reward systems in science have incentivized individual endeavors seeking scientific discovery. If one publishes a new finding, he or she takes all the recognition and rewards; there are no second prizes in science (Strevens 2003). This winner-takes-all system has been inherently built in science, so that individual scientists often attempt to withhold research materials until they fully appreciate the benefits of the materials and take first place (Blumenthal et al. 2006; Hagstrom 1974; McCain 1991; Mitroff 1974). Scientists' material-withholding becomes more apparent in a recent decade (Blumenthal et al. 2006; Campbell et al. 2002; Walsh, Cohen, and Cho 2007) as private returns from patenting, licensing and other commercial activities have been widely recognized as an alternative reward in science (Stephan and Everhart 1998).

Given the competitive research environment, material-sharing is not always motivated by an altruistic attitude or a commitment to open science. Instead, individual researchers may share their research materials with their competitors in order to prevent duplicate works, increase their visibility and take a scientific and commercial lead in the field  (Haeussler et al. 2009; Hilgartner and Brandt-Rauf 1994; Hull 1985; von Hippel 1987). Sharing with one entity does not always mean sharing with others. Scientists often share their research materials only with selected entities (Haeussler et al. 2009). In other words, material withholding appears to simultaneously occur with material-sharing. Material-sharing with selected entities may reflect a cooperative research arrangement in a competitive environment. Scientists may strategically select their partners with which they want to share their genetic materials and coproduce scientific or commercial products out of the shared materials. Previous literature (Haeussler et al. 2009; Hagstrom 1974; Oliver 2004; Strevens 2003; von Hippel 1987) reports that this kind of strategic or exclusive material-sharing is commonly found in a competitive research environment; this is because individuals tend to increase their competitive advantages and a chance to win the prize in the field by forming a collaborative team or coalition.

Given the dual reality in which scientists are engaged in both material-withholding and sharing, this dissertation specifically focuses on the situation in which scientists obtained genetic materials from others but agreed not to share them with a third party. This is defined as exclusive sharing in that genetic materials are shared between an original provider and a receiver but not with a third party. Exclusive sharing of genetic materials is closely related to the previous concepts, namely, "excludability" in material transfer (Walsh, Cohen, and Cho 2007) and "specific sharing" (Haeussler et al. 2009). However, an inquiry into exclusive sharing has unique value in that it helps further identify the moment at which the flow of genetic materials is blocked and the benefits of the materials are enclosed by a group of individuals.

Exclusive sharing is a type of material-sharing that occurs only among selected entities.[7] It embodies a micro-level bilateral interaction through which one party makes materials available only to a selected party. Exclusive sharing can differ from open sharing that is open to the general public.

The operationalized concept of exclusive sharing can be described as shown in Figure 2. Similar to other types of resource-sharing or transfer (Bozeman 2000; Ipe 2003), exclusive sharing comprises four sub-components: 1) sharing actors (i.e., material senders and receivers), 2) shared materials/objects (i.e., genetic materials), 3) sharing process and 4) the environment in which sharing occurs.

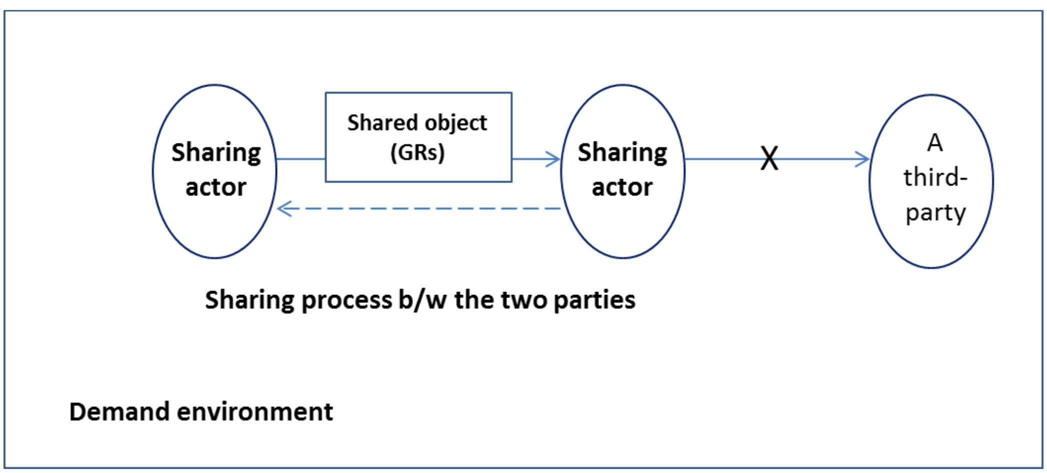


Figure 2. Four Components of Exclusive Sharing

[7] Material-sharing and material-transfer are interchangeably used in this dissertation. Although sharing often refers to bilateral or multilateral interactions among individuals, whereas material-transfer is often used to describe the flow of the materials, this distinction between material-sharing and material-transfer is quite blurry. This is because the two terminologies are not substantially sophisticated as legal or theoretical terminologies. One terminology is often preferred to another simply because of the different focus of research (i.e., shared objects versus sharing actors). Therefore, it would be possible to use the two different terminologies when describing the same phenomena of material sharing.

Exclusive sharing without a third party transfer is specific enough to capture a micro-level bilateral interaction or a group dynamic which inevitably involves a chance to exclude or be excluded. At the same time, exclusive sharing remains a broad concept in that it does not assume a specific relationship between original material providers and receivers; the two parties that share the materials may or may not possess a shared ownership over the materials. Material-sharing can even occur among researchers who do not know each other and do not share social norms that promote material-sharing (Shibayama and Baba 2011; Wasko and Faraj 2005). Additionally, one-time transfers between individuals may occur without specific expectations of reciprocity (Wasko and Faraj 2005). Hence, the operationalized concept of exclusive sharing in this dissertation is broad enough to capture a wide range of sharing relationships among individuals but narrow enough to distinguish it from other macro-level approaches on material transfer at the field level.

### 2.2.3. Theoretical Foundations of Exclusive Sharing

Previous literature provides diverse theoretical frameworks on exclusive sharing, though most of it does not directly address issues on genetic materials. Studies in different disciplines, such as economics, sociology, political science and policy studies, have examined why and how individual entities share resources with others on an exclusive basis. These intellectual endeavors have led to theories on transaction costs (Jones 1983; Williamson 1979), social exchange (Emerson 1976; Molm 2003; O'Brien and Kollock 1991), science institutions (Merton 1940; Rodriguez 2005; Ziman 2000) and socio-ecological systems (Janssen and Ostrom 2006; Ostrom 2009).

#### (1) Transaction Cost Theory

Transaction cost theory largely originated from the seminal works of Williamson (Williamson 1979, 1981). Although transaction costs were commonly acknowledged in economics (Coase 1937), Williamson (1979) revisited the concept of transaction costs and systematically applied it to quasi-market conditions where individual choices are constrained by their experiences and institutional settings.

Basically, transaction cost theory states that each market or quasi-market transaction accompanies a certain level of processing costs, namely, transaction costs (Williamson 1979). Transaction costs are a kind of market externality (Allen 1991; Zerbe and McCurdy 1999); they increase when the market fails to fully incorporate all the expenses required for one transaction. Transaction costs can occur even before individuals engage in any transactions because the individuals first need to identify potential actors and feasible transaction channels. Transaction costs also include the technical, administrative and socio-political costs associated with transactions.

Individuals are likely to "economize" transaction costs (Williamson 1979). Consideration of transaction costs influences a wide range of decisions surrounding market transactions and contracts (Macher and Richman 2008; Williamson 1981) and even research collaboration (Belkhodja and Landry 2007; Cabrera and Cabrera 2002; Pisano 1991). Williamson (1979) argues that transaction costs adjust the size of groups that share resources. And the selection of governance structures (e.g. hierarchical government, bilateral contracts, and an autonomous market) is seen as a strategic choice to reduce transaction costs for different types of transactions (e.g. recurrent versus temporary transactions, and transactions with specific or anonymous partners).

According to transaction cost theory, each individual is a self-interested utility maximizor. Individuals aim to maximize their benefits from the use of resources while minimizing costs for their use. Nevertheless, Williamson (1981) admits that individual decisions to minimize transaction costs are not entirely rational. Instead, individuals have limited cognitive capacity to search for and comprehend necessary information; they are subject to "bounded rationality" (Simon 1957). They are constrained by personal knowledge, experiences, and societal surroundings. Individuals attempt to make the optimal choices but are more likely to choose a "seemingly best" – not necessarily "the best" – option given specific cognitive, organizational, and societal constraints. Nonetheless, they still remain "intendedly rational, but only limitedly so" (Simon 1957, xxiv).

From the transaction cost approach, exclusive sharing of genetic materials between two individuals can be an individual decision made based on one's perception of benefits and costs.

Individuals' cost estimation includes multiple types of transaction costs. General information costs are incurred when individuals search for potential transaction actors, channels and outcomes. Transaction costs may also occur as part of investment in transportation and storage of genetic materials. Transaction costs can include administrative costs related to making contracts or contacts as well as any regulation-related costs associated with compliance and non-compliance with diverse policies. Moreover, transaction costs may include potential court costs or a loss of scientific reputation and market share caused by sharing partners' opportunistic behaviors. On the other hand, consistent legal or organizational frameworks that clearly specify ownership, responsibility, obligations and due procedures can reduce transaction costs (Williamson 1979; Zerbe and McCurdy 1999). Accumulated transaction experiences and trustworthy relationships among transaction partners can also decrease transaction costs (Dyer and Chu 2003; Williamson 1981).

Sharing occurs only when two parties expect the benefits of sharing to outweigh the costs. Material-sharing can be a strategic choice made by two parties in order to mitigate the total expected cost of transactions. Exclusive sharing is likely to occur when two parties that have already engaged in transactions consider that a third party transfer is too costly or risky to compensate for the expected benefits.

The transaction cost approach (Williamson 1979) is useful to examine varied patterns of exclusive sharing observed at the individual level, ranging from bilateral transactions to a large-scaled hierarchical organizations. It also helps understand diverse patterns of material-sharing, ranging from one-time transaction without any subsequent obligation (Zerbe and McCurdy 1999) to repetitive transactions among selected members (Pisano 1991). Transaction cost theory is particularly useful to explain a hybrid arrangement in which genetic materials are shared with selected entities but not with all the parties.

Nonetheless, transaction cost theory loses its efficacy in investigating multi-layered social relationships and regulatory institutions because it oversimplifies social relationships and institutions as byproducts of individual economic decisions. Despite the widespread use of the theory in various contexts such as business management, finance, and research collaboration across different nations, transaction cost theory poorly identifies legal and political institutions influencing bilateral or multilateral interactions among individuals and organizations (Macher and Richman 2008). Transaction cost theory tends to reduce all the societal values into economic terms. This economic reductionism grounded in transaction cost theory limits our understanding of affective interactions, social obligations and recognition-seeking behaviors. Moreover, like other economic theories, transaction cost theory sacrifices an error of methodological individualism for its clarity and simplicity.

### (2) Social Exchange Theory

The social relation school associates exclusive sharing with interpersonal relationships (Cook and Whitmeyer 1992; Emirbayer 1997; Homans 1958). Relational attributes associated with sharing behavior include: closeness, trustworthiness (Andrews and Delahaye 2000), authority, power relations (Lawler and Yoon 1993; Molm, Peterson, and Takahashi 1999), homophily and heterophily (Bacharach, Bamberger, and Vashdi 2005; Ibarra 1993). It is proposed that these relational attributes are conducive to a certain form of sharing which can again change existing relationships. In other words, social relations are an antecedent as well as a consequence of exclusive sharing; exclusive sharing is an endogenous component of social relations.

In particular, social exchange theory highlights “reciprocity” as a relational attribute that promotes the sharing of resources among individuals (Emerson 1976; Homans 1958; O'Brien and Kollock 1991). Homans (1958) notes that material-sharing is not only an economic behavior but also a social behavior because both a provider and a receiver are under a certain social norm of fairness/reciprocity in society. Individuals that are giving much to others try to get much from them, while individuals that get much from others are under pressure to give much back (Homans 1958, 606). Even so, a sense of fairness or reciprocity is not solely about an individual’s rational decision-making; individual perceptions of reciprocity are rather interdependent with each other. A sense of fairness or reciprocity is not simply translated into economic terms either. Rewards from a recipient can include not only economic rewards but also emotional affection, social recognition, and political support or obedience (Blau 1964; Homans

1958; O'Brien and Kollock 1991). Based on this insight, Blau (1964) summarizes that “social exchange is contingent on rewarding reactions from others” (Blau 1964, 6).

Social exchange can differ from economic transaction in many respects (Das and Teng 2002, 448). Social exchange may or may not involve tangible economic benefits, and rewards from social exchange may or may not be negotiated among actors (Molm, Peterson, and Takahashi 1999). Social exchange often embodies “unspecified obligations” which are not stipulated in advance (Blau 1964, 93; Bouty 2000). Sometimes, rewards from social exchange are given without being prompted; sometimes, it takes a long time for rewards to be offered (Gouldner 1960). In fact, individuals’ reactions to expected rewards involves a great deal of uncertainty and risk (Fehr and Gintis 2007; Molm 2003). More often than not, individuals are unable to predict when and in what kind of reciprocal returns will be realized. More importantly, social exchange depends on interactions among individuals which cannot be predetermined.

Social exchange theory differs from transaction cost theory in that it focuses on interdependent relationships instead of independent individual decision-making. Social exchange theory views individuals as social actors who are connected with each other and who care about others (Emerson 1976). Social exchange theory has been applied to various forms of resource-exchange and material-sharing that occurs in market, quasi-market and non-market conditions (Das and Teng 2002).

Reciprocal exchange with tangible and immediate rewards is proposed to engender subsequent sharing (Emerson 1976; Molm, Peterson, and Takahashi 1999). Even the presence of expected future rewards is found to motivate individuals to share their resources with others (Das and Teng 2002; Gouldner 1960; Yamagishi and Kiyonari 2000). On the other hand, failure to reciprocate is seen as harming trustworthy relationships and eventually leads to exclusion from future exchanges (Blau 1964, 108).

From a social exchange perspective, exclusive sharing of genetic materials among scientists can be understood as a reflection of social relations, especially reciprocal relationships. When one has a reciprocal relationship with another, one is more likely to make resources available to the other (Bouty 2000; Shibayama and Baba 2011). On the one hand, one’s willingness to share can be extended to a group of people who possess a similar expectation of future rewards (Das and Teng 2002; Yamagishi and Cook 1993). On the other hand, individuals who have already shared their resources may withhold the shared resources from others if they expect that their offers will not be reciprocated. In this sense, exclusive sharing resembles an uneven distribution of reciprocal relationships among societal actors.

Nonetheless, there is a caveat when one applies a social exchange perspective to a prediction of exclusive sharing. Reciprocity is proposed as a precondition as well as a consequence of material-sharing, which raises a concern on tautology. If one posits that an actor, A, is going to provide its resources to an actor, B, because B already gave or will give A any rewards in return, this proposition self-justifies nothing but a concept of reciprocity. Moreover, if one's willingness to share is explained by the other's willingness to share, researchers will encounter a causality dilemma. Which would come first, the chicken or the egg? Acknowledging these problems, Emerson (1976) recommends not using reciprocity as a normative assumption but consciously using it as an explanatory variable which predicts other social phenomena. Therefore, it is important to be cautious when modeling reciprocity, given its endogenous nature in sharing behavior.

Moreover, reciprocity between two parties is only a partial aspect of reciprocity that exists in society. It might be possible that two parties are more likely to engage in material-sharing even when they do not have a reciprocal relationship with each other; they can be indirectly connected with each other when they have a reciprocal relationship with the same trustworthy third party. It is also possible that the two parties are motivated by a general societal norm of reciprocity without any bilateral interactions between them (Gouldner 1960). Therefore, it is important to acknowledge that bilateral interaction is not the only way through which individuals are connected with one another. Individuals can be indirectly connected via a third party; they can also engage in material-sharing with a third-party when they are under the influence of societal norms promoting material-sharing.

**(3) Institutional Theory: Science Institutions**

Individuals' decision about whether to share is not solely determined by individual or inter-personal factors but also by the broader institutional context. This institutional perspective has continuously developed in social studies of science (David 2004; Merton 1942; Polanyi 1962; Ziman 2000) and applied to an empirical research on material-sharing in science (Chubin 1985; Rodrigues 2007; Walsh, Cohen, and Cho 2007).

Institutions refer to formal and informal rules, routines, conventions and norms (North 1990). They are basically implicit and explicit guidelines on what is appropriate and meaningful in society (March and Olsen 1989; Scott 2003). Institutional theory considers that cognitive frameworks, normative attitudes, and symbolic logics are essentially conditioned by the institutional contexts in society (Scott 1995).

Since individuals cannot comprehend all the consequences of their decisions in advance and make a rational decision on complex societal matters, they tend to rely on past and current conventions and practices. Individuals continuously attempt to minimize risk and uncertainty in decision-making by conforming to granted rules, conventions, and norms as well as imitating others' past practices (Oliver 1991). They also legitimize their decisions consciously and unconsciously and give meaning to their experiences by referring to granted conventions and institutions in society (Scott 1995). In this sense, institutions serve as a "logic of appropriateness" instead of a "logic of consequence" (March and Olsen 1989).

In a scientific community, at least two competing institutions have been identified in previous studies: open science vs. proprietary (Rodriguez 2005). Open science institutions have traditionally advocated for unrestricted access to prior knowledge and research materials for scientific advancement (Merton 1942; Polanyi 1962). However, the tradition of open science has been increasingly challenged by continuously expanding proprietary institutions (David 2004; Kitch 1977; Ziman 2000). Property rights over biological materials have extended into national and international patent laws and policies. Commercialization of research using biological materials is now prevalent in private, public and nonprofit research organizations (Hong and Walsh 2009; Jackson 2003).  Ziman (2000) articulates that the shift from open to proprietary institutions legitimizes commercialization and privatization of research findings (Hessels and van Lente 2008). The increasing dominance of proprietary institutions in science is expected to discourage researchers from passing on genetic materials (or information and other inputs) to peers without compensation (Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007). Therefore, it can be said that scientists' exclusive sharing now lies on a Mertanion-Zimman continuum where two competing institutions create varied constraints as well as opportunities for individuals' access to genetic resources (Rodrigues 2007).

Given the surge of proprietary institutions in science, some policy studies are raising concerns about the negative effects of exclusive rights on scientific production. One well-known argument from Heller and Eisenberg (1998) asserts that, "contrary to a tragedy of the commons, a tragedy of the anti-commons is prone to occur in science when multiple owners each have a right to exclude others from a scarce resource and no one has an effective privilege of use" (p. 698). It laments the potential under-utilization of prior research caused by exclusive sharing of research materials. Similar concerns are found in several policy discussions and in empirical research (Chubin 1985; Eisenberg 2006; Grobstein 1985; Lei, Juneja, and Wright 2009; Marshall 1999; Rosenberg 1996). These works connect the issue of material-sharing with a critique of contemporary proprietary institutions; proprietary institutions are blamed with discouraging scientists from sharing their research materials with their peers, thus hindering scientific validation. This, in turn, dampens the circulation of ideas, materials, and data among scientists, and ultimately prevents scientific advancement. These studies (Chubin 1985; Eisenberg 2006; Grobstein 1985; Lei, Juneja, and Wright 2009; Marshall 1999; Rosenberg 1996) also raise concerns about auxiliary issues, such as proprietary reward systems that promote private returns at the expense of public benefits, and privatization of government-funded research and research materials. Most of these works (Chubin 1985; Eisenberg 2006; Grobstein 1985; Marshall 1999) are rather normative but reveals the needs to answer critical questions: "Does material-sharing promote scientific advance as claimed?", and "Does exclusive sharing deter scientific discovery?"

The institutional approach reviewed here identifies macro-level institutions that influence individuals' sharing behavior. It succinctly summarizes a transition of science institutions from open science to proprietary institutions (Rodriguez 2005; Shibayama 2012; Ziman 2000), which can influence individuals' exclusive sharing (Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007). The institutional approach also reveals the need to assess the negative effects of exclusive sharing on research outcomes.

Nevertheless, the institutional approach (Rodriguez 2005; Shibayama 2012; Walsh, Cohen, and Cho 2007) heavily relies on a dichotomy of open science versus proprietary institutions; it simply assumes that individuals tend to engage in either material-sharing or material-withholding but not both. Therefore, previous literature fails to uncover micro-level group dynamics simultaneously occurred for material-sharing and material-withholding. Moreover, previous literature on material-sharing among scientists (Blumenthal et al. 2006; Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007) does not pay much attention to the attributes of genetic materials. Most studies focuses solely on social institutions. It is necessary to understand socio-ecological attributes of genetic materials to better understand how and why some materials are more openly exchanged than others, given the broad range of genetic materials used in science.

**(4) Socio-Ecological System Theory**

Socio-ecological system (SES) theory takes into account not only social institutions and actors but also biophysical environments in which individuals and institutions are placed (Berkes and Folke 1998; Dietz, Ostrom, and Stern 2003; Ostrom 2009). Biophysical environments are considered to be a precondition to the development of social institutions which, in turn, lead to a change in biophysical environments (Berkes and Folke 1998; Ostrom 2009).

SES theory differs from environmental determinism, although it redirects our attention from social institutions to biophysical environments. First, unlike environmental determinism, biophysical environments are understood to coevolve with social institutions (Berkes, Folke, and Colding 1998;

Ostrom 2009). Hence, the state of biophysical conditions depends on the way they are accessed, used and exchanged in society; human interventions are an important element of socio-ecological systems. Second, SES theory emphasizes dynamic interactions among subcomponents as well as the integration of a whole system (Berkes and Folke 1998). Third, SES theory acknowledges that the coevolution of social and ecological systems over time embraces continuous adaptation processes in a specific location; in turn, this creates a location-specific and culture-specific trajectory of resource management history (Kirk and Memon 2010; Murdoch, Marsden, and Banks 2000).

A complex socio-ecological system is composed of four main subsystems (Ostrom 2009): 1) resource units (e.g., lobsters), 2) a resource systems (e.g., a coastal fishery), 3) users (e.g., fishermen), and 4) governance systems (e.g., organizations and rules that govern fishing on a particular coast). Multiple attributes of all four subunits can affect the likelihood of users' engagement in any type of collective action. In addition, an interaction among the subunits is also modeled as a critical component that influences users' collective actions and subsequent outcomes, such as sustainability or resilience of socio-ecological systems.

Empirical research based on SES theory (Johnson et al. 2012; Schlager, Blomquist, and Tang 1994) shows that, individuals tend to lose autonomous control over the stock and flow of resource units when resource systems are too complex to comprehend. Complexity of resource systems increases when the systems are closely interconnected with surrounding environments (e.g., *in-situ* conservation fields) so that their boundaries are not clearly delineated. Individuals' control over resource units is also limited when resource systems are not technically visible or detectable because of their hidden components (e.g., groundwater systems) or their sporadic and temporary presence (e.g., volcanos, disease outbreaks). In addition, Altrichter and colleague (2008) suggests that mobility of resource units matter. Individuals are more constrained in comprehending a whole resource system and controlling entry to the system, when they have mobile resource units (e.g. wildlife, migratory birds, and fish) than they are when having stationary resources within a clear boundary (e.g. plants, tree, ground water).

However, these identified tendencies do not mean that biophysical environments are the single most important factor. Rather, SES theory emphasizes that the impacts of biophysical environments are highly contingent on the attributes of user communities, socio-economic rules and incentives, monitoring and sanctioning mechanisms and governance structures (Basurto, Gelcich, and Ostrom 2013; Dietz, Ostrom, and Stern 2003; Janssen and Ostrom 2006; Ostrom 2005). Hence, the SES theory suggests linking biophysical environments with social institutions instead of treating them separately in order to better understand the diverse use and exchange patterns of natural resources.

From a socio-ecological system perspective, individuals' exclusive sharing can be seen as a reflection of the interplay between ecological and social systems. SES perspective is particularly relevant to understanding exclusive sharing of genetic materials because the ecological attributes of the materials vary significantly across organisms, locations, and sporadic events.

Nonetheless, the analytical utility of SES theory is forsaken by its comprehensiveness (Padmanabhan and Jungcurt 2012). SES theory attempts to identify all the relevant socio-ecological variables and listed thirty to forty socio-ecological factors to be considered (Basurto, Gelcich, and Ostrom 2013; Ostrom 2009). This everything-matters approach may help describe empirical observations but does not help predict a certain behavior. Moreover, despite an emphasis on complex interactions and multiple feedback loops in a socio-ecological system, SES theory remains silent on the matter, "how to analyze the feedback and interactions and obtain generalizable knowledge from different cases". Therefore, the SES theory does not provide a useful analytical tool to identify a meaningful causal relationship from multiple cases, although the theory offers a valuable insight on the interplay between social institutions and ecological systems.

#### 2.2.4. Summary

In summary, at least four major theories provide relevant insights into exclusive sharing of genetic materials. Institutional theory of a scientific community directly addresses the issue of material-sharing among scientists, whereas the other three approaches provide a general view on resource-sharing.

In addition, institutional theory of the scientific community provides theoretical motivation to investigate the consequences of exclusive sharing on research outcomes.

Table I summarizes the main arguments of each theory. Each theory uncovers a different level of social mechanisms that may occur at individual, organizational and societal levels. The assumption about individuals' autonomy in decision-making becomes weaker as the foci of theories move from individuals to macro-systems. Macro-level theories illuminate more collective aspects of sharing, whereas micro-level theories focus more on individual choice and interpersonal relationships which may or may not be aligned with institutional arrangements.

TABLE I. SUMMARY OF TEHORETICAL FOUNDATIONS

| | Motivations of Sharing | Sharing As |
|---|---|---|
| Transaction cost theory | Transaction costs | Individual choice (economic behavior) |
| Social exchange theory | Reciprocal relations | Interpersonal decision (social behavior) |
| Institutional theory | Science institutions | Individual compliance with social institutions |
| SES theory | Socio-ecological systems | Reflection of the interplay between social institutions and ecological systems |

These theories are not necessarily in competition with each other; instead, they are more or less complementary. Individuals can be autonomous decision-makers in some contexts, but in others individuals are influenced by their partners, peers, and socio-ecological surroundings. Moreover, self-interested choice can coexist with norm-regarding behavior (Fehr and Gintis 2007). Although the institutional approach focuses only on the macro-level of social institutions and overlooks micro-level interactions among individuals, two identified micro-level theories – transaction cost theory and social exchange theory – fill the gap between prior institutional literature and reality. Transaction cost theory focuses on individual decision-making (i.e., individuals are seen as a relatively autonomous agent who makes a choice based on expected costs and benefits), whereas social exchange theory focuses on bilateral reciprocal relations that are conducive to resource-sharing among individuals. In addition, socio-ecological system theory illuminates another condition, namely, ecological systems and presents an integrated framework to explain social behavior not only with social institutions but also with ecological conditions.

Therefore, an integrated approach is necessary to understand both micro- and macro-level aspects of exclusive sharing. This dissertation develops an integrated perspective based on the four theories. Figure 3 describes the underlying theoretical foundations of exclusive sharing incorporated in this dissertation.

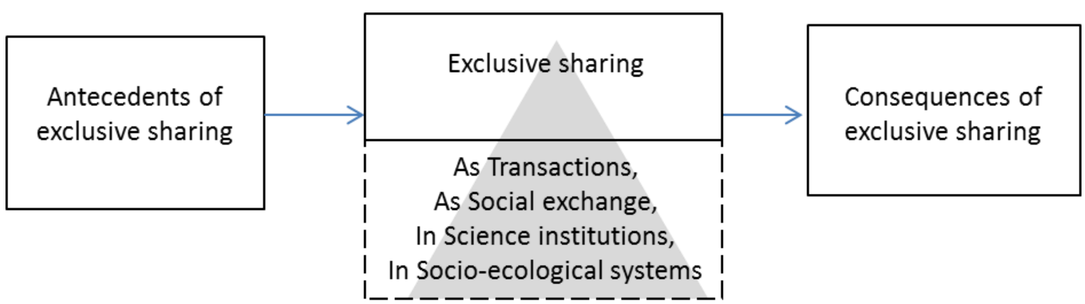


Figure 3. Theoretical Foundations of Exclusive Sharing

The four theories reviewed in this chapter help develop a baseline understanding about which social and ecological factors will lead to exclusive sharing, although they are not directly tested in an empirical analysis. For example, transaction cost theory shows the extent to which transaction costs are required matter for exclusive sharing. Various factors, such as geographic distances, information reliability, trustworthy relationships, and formalized rules and procedures, can be associated with transaction costs, and eventually with the likelihood of exclusive sharing. At the same time, social exchange theory suggests that reciprocal relationships can shape sharing patterns. Socio-ecological attributes of genetic materials can also lead to a certain pattern of sharing. Last but not the least, institutional theory suggests that institutions of a scientific community can engender exclusive sharing behaviors which, in turn, influence research outcomes. Based on these theories, the next chapter develops testable hypotheses on the antecedents and consequences of exclusive sharing.

# 3. HYPOTHESIS DEVELOPMENT

This chapter provides an overview of the previous empirical research largely stemming from the theoretical foundations introduced in the previous chapter; however, it presents a more concrete view of the observed phenomena. Based on the literature review, this chapter develops propositions and hypotheses on the effects of the antecedents. It also develops testable hypotheses on the consequences of exclusive sharing on research outcomes. At the end of this section, presented is a conceptual framework explaining the process through which socio-ecological attributes of multiple sharing components influence scientists' exclusive sharing and affect particular research outcomes (i.e., publications and intellectual property outcomes).

## 3.1. Antecedents of Exclusive Sharing

What makes material-sharing among scientists exclusive? The most common answer provided in the previous studies is science norms and institutions: open science vs. proprietary (Rodriguez 2005). Open science institutions (Merton 1942) tend to encourage scientists to share their research materials with others without any restrictions or delay. On the other hand, emerging proprietary institutions (Ziman 2000) are reported to hinder scientists' ability to obtain genetic resources for their research (Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007). Previous studies on material-sharing provide a baseline for our understanding of the institutional environments influencing individual behaviors (Rodrigues 2007; Walsh, Cohen, and Cho 2007).

Nonetheless, prior literature presents only a partial view of exclusive sharing. It focuses only on macro-level institutions and does not take into account multiple sub-components of sharing. Not only the macro-level institutional environment but also micro-level actors and processes are important in predicting the likelihood of exclusive sharing (Goldberg 1997; Haas and Park 2010; Tucker 2009). At the same time, various natural traits of genetic materials can create different patterns of social interaction and exclusive sharing (Hilgartner and Brandt-Rauf 1994; Welch, Shin, and Long 2013). Acknowledging the multiple components of sharing, this dissertation proposes that exclusive sharing is influenced by the varied attributes of multiple subcomponents: 1) sharing actors – material senders and receivers, 2) shared materials/objects (i.e., genetic materials), 3) sharing process and 4) the demand environment in which sharing occurs. Attributes of each component are proposed to influence whether genetic materials are exclusively shared.

### 3.1.1. Attributes of Genetic Materials

A broad range of genetic materials are used by scientists in the field of food and agricultural research. They vary in terms of biological and ecological traits. They also vary in terms of economic and societal value. From a socio-ecological system perspective, varied socio-economic attributes of genetic materials are intertwined with different ecological attributes of the materials (Berkes and Folke 1998; Dietz, Ostrom, and Stern 2003; Ostrom 2009). These socio-ecological attributes of genetic materials can engender specific sharing patterns (Janssen and Ostrom 2006; Ostrom 2009).

With a well-established price system for stable and uniform genetic components, market value can represent the actual worth of genetic materials. Nevertheless, genetic materials in agricultural research are not always end-products which can be purchased via market. Much of the materials remain in quasi-market or non-market conditions. And some genetic materials are only available in nature given its reliance on a specific geo-ecological system. Even when scientists extract genetic materials from nature and conserve them in a stable *ex-situ* conservation repository, scientists can obtain the materials from public gene banks without substantial costs; they also share the materials with their colleagues in an informal manner via peer-to-peer networks (Shibayama and Baba 2011; Stern 2004; Welch, Shin, and Long 2013). Therefore, many of the materials used in agricultural research are neither priced nor available in a market. Hence, the potential value of genetic materials needs to be examined with non-market as well as market indicators. Both market and non-market values of genetic materials are expected to encourage or discourage individuals from being involved in any type of material-sharing (Haeussler et al. 2009; Hilgartner and Brandt-Rauf 1994). In addition, the significance of ecological conditions is proposed to influence exclusive sharing behavior. Scientists' access to genetic materials can be more contingent on the conditions of ecological systems and the interplay between ecological systems and social institutions when they seek genetic materials of which values and viability heavily depends on specific ecological conditions.

### (1) Market and Non-market Values

Market and non-market values of genetic materials are used to indicate their worth. This include not only commercial market value but also values that are not reflected on market prices but meaningful for new scientific discovery, education and training, community services, and environmental conservation (ten Kate 2002).

The potential or actual commercial value of genetic materials has been long recognized in the agricultural industry and further emphasized along with the expansion of the bio-technology and pharmaceutical industries (Glenna et al. 2007; Stephan and Everhart 1998). At the same time, the non-market value of genetic materials for use in new scientific discovery and research has also been increasingly recognized in the research community (ten Kate 2002). Valuable information and knowledge embedded in genetic materials are viewed as helping scientists advance knowledge, although the value of information might not be immediately transformed into tangible rewards. Scientifically valuable genetic materials and information help scientists obtain social rewards, such as reputation or visibility in the field, or even intrinsic rewards that accompany knowledge production and discovery (e.g., quest for the truth). The non-market value of genetic materials may be more important for scientists who are often motivated by social or intrinsic rewards rather than monetary ones (Goldberger et al. 2005; Lam 2011; Stephan and Levin 1996).

Since scientists are, in part, self-interested utility-maximizers (Tullock 1993), market and non-market values of genetic materials can motivate them to withhold the materials and exploit the value of materials before passing them on to third-parties. The more valuable the genetic materials are, the greater the competitive edge in science and industry (Haeussler 2011). Previous studies suggest that scientists are more likely to withhold research materials of high value from others; they tend to appreciate the advantages of a temporary monopoly before publicizing the materials via publications and other scientific outputs (Haeussler et al. 2009; Hilgartner and Brandt-Rauf 1994).

Hilgartner and colleague (1994) criticize much of the literature on material-sharing because it does not pay attention to the characteristics of shared materials. It argues that the attributes of research materials can affect scientists' willingness to share, and proposes that scientists are less likely to share research materials – including genetic materials – with others when they perceive the materials to be of potential or actual value. A similar insight is also found in the previous study on knowledge-sharing (Ipe 2003); it proposes that the potential and actual value of knowledge can provoke researchers to claim their exclusive ownership over knowledge while dampening individuals' willingness to share.

In a more specific context in which scientists compete for the first discovery or invention, Haeussler and colleagues (2009) show that scientists become reluctant to share as the perceived value of the research materials increases. That work describes scientists' sharing as a specific sharing game in which scientists compete for a prize awarded only to the first problem-solver. In the game, scientists compete with each other while strategically collaborating with others in order to increase their chances to win. In this situation, individuals share their research materials with other partners only when they expect the benefits overweigh the costs (McCain 1991). When individual scientists perceive genetic materials to be of high value, they tend to withhold the materials from others. In other words, material-sharing may decrease the odds of winning given the condition in which the prize is only granted to the first discovery or invention. The greater the perceived value of the genetic materials, the greater potential loss from sharing expected by scientists. Therefore, Haeussler and colleagues (2009) argue that scientists are less likely to share their genetic materials with other peers when they perceive that the materials embody greater competitive advantages. In a following research, Haeussler (2011) shows that scientists in both university and industry are each less likely to share their research materials when they perceive greater competitive values of the materials.

Although previous research does not directly assess the complex group dynamics that can occur among more than two actors, it suggests that a positive association between the value of the requested material and material-withholding behavior is plausible. Just as researchers withhold research materials of actual or potential value from other competitors (Haeussler 2011; Hilgartner and Brandt-Rauf 1994; Ipe 2003; von Hippel 1987), they may likewise withhold materials from a third party. If material providers perceive the value of their materials, they may ask their recipients not to share the materials with a third party. Similarly, when material receivers perceive the value of the materials, they also may be reluctant to pass them on to other third parties. In both cases, genetic materials that are highly valued would be more likely to be shared in an exclusive manner, without being transferred to a third party. Therefore, genetic materials with higher market and non-market values are posited to be positively associated with exclusive sharing.

*Proposition 1a. Genetic materials with higher market value will be more likely to be shared exclusively.*

*Proposition 1b. Genetic materials with higher non-market value will be more likely to be shared exclusively.*

**(2) Significance of Ecological Condition**

Socio-ecological system theory suggests that genetic materials (i.e. resource units) are inherently connected with socio-ecological systems (Berkes, Folke, and Colding 1998; Ostrom 2009). However, the degree to which genetic materials are attached to specific ecological conditions varies depending on the way in which the materials are conserved and utilized.

A significance of ecological conditions can indicate the degree in which genetic materials (i.e., units) are linked to geo-ecological environments (i.e., systems or habitats). Ecological conditions include specific natural environment, geographic areas, and natural events in which specific genotypes and phynotypes of genetic materials can persist. They also include diverse natural landscapes in which genetic variations and diversity that are sustained and evolved.

In agricultural research, ecological conditions from which genetic materials originate have been treated in two different ways. On the one hand, many of genetic samples have been removed from their natural habitats, extracted from whole organisms, categorized and conserved in *ex-situ* collections in modern science (Stern 2004). Lab work further disaggregates geo-ecological attributes of genetic materials, selectively combines separate subunits of organisms, sometimes nurtures and manipulates the subunits in an artificial environment, and develops them into stable and controllable research tools (e.g., reagents, cell lines). Multiple conservation methods, including cryoconservation, have been developed in order to expand the kind of genetic materials that can be stored in *ex-situ* facilities and transferred across regions. Commercialization of genetic materials has further facilitated the extraction of specific ecological traits from nature and the development of stable and consistent elite lines (Long and Blackburn 2011).

On the other hand, the significance of geo-ecological conditions has been increasingly recognized especially in landscape ecology, conservation science, and sustainable agriculture (Maxted, Ford-Lloyd, and Hawkes 1997). Some researchers study selective gene expressions, unique genetic makeups and phynotypes of a specific organism that are only viable in specific geo-ecological environments. Genetic diversity found in various natural habitats is of high interest to researchers who study ecological evolution and resilience. Acknowledging the significance of ecological conditions, *in-situ*, or on-site conservation has increasingly been promoted in agricultural science (Murdoch, Marsden, and Banks 2000).

In sum, in some ways the ecological conditions of genetic materials have been deemphasized in most of modern agricultural science, while in other ways they have been reemphasized in conservation research. Nowadays, genetic materials used in agriculture research significantly vary in terms of the degree to which the materials are linked to specific ecological conditions. Although all genetic materials originate from natural environments in an ecological sense, some materials are maintained in *ex-situ* facilities without intense interactions with their natural habitats whereas other materials are conserved only in specific geo-ecological conditions.

Environmental economics suggests that resources conserved in nature likely remain as non-exclusive public goods or common pooled resources (Goodstein 2011; Kolstad 2000; Stavins 2011). This is because the complexity and unpredictability in natural ecosystems hinder individuals' comprehension of the stock and flow of natural resources, which substantially limits their ability to define ownership or exclusive rights over the resources (Basurto, Gelcich, and Ostrom 2013; Stavins 2011); it is also challenging to develop appropriate monitoring and sanctioning mechanisms protecting the exclusive rights within a complex natural ecosystem. A local fishery provides a typical example of a common-pool resource in which stock and flow are so densely interconnected with local ecosystems that it is challenging to predict and monitor all the possible access to the fishery (Basurto, Gelcich, and Ostrom 2013; Kirk and Memon 2010; Rudd 2004). Mobile wildlife, avian species, and virus strains are another example in which movements are not easily monitored and predicted, thus rendering it costly to maintain exclusive access to the resources (Altrichter and Basurto 2008; Schlager, Blomquist, and Tang 1994).

Socio-ecological system theory further elucidates the societal implications of ecological traits. Challenging prior concerns about overexploitation of common goods (Hardin 1968; Smith 2012), socio-ecological system literature shows that natural resources conserved in local environments can be shared among local users in a more inclusive and collective way (Bodin and Crona 2009; Kirk and Memon 2010; Ostrom 1990). Pretty's (2003) extensive review of current practices shows that in developing countries, users of common-pooled resources (e.g., local fishery, forestry and irrigation water) are more densely connected with each other than expected; they share resources, develop a densely connected local network of users, and build greater trust among themselves. If the dense network of material users is established, both an original material provider and a receiver are likely connected with a third party, which may engender a subsequent material-sharing with a third party. Cohesive and dense networks of resource users are also documented in a scientific community that highly values the diversity of biological-control agents (Cock 2010). Bio-control researchers often rely on materials obtained from other regions and other researchers. They also provide their materials to other researchers. Given the interdependence among researchers, unrestricted access to biological control agents has been long established in a research group on bio-control (Cock et al. 2010).

Therefore, it is plausible to associate the significance of ecological conditions with less exclusive sharing patterns. This is partly because genetic materials only viable in certain ecological conditions are more likely to remain non-exclusive common goods (Kolstad 2000; Stavins 2011). This is also because a reliance on complex and unpredictable ecological conditions appears to increase inter-dependency among material-users and motivate them to share their materials (Bodin and Crona 2009; Ostrom 1990; Pretty 2003).When the ecological conditions from which genetic materials originate are considered to be critical, the genetic materials are posited to be less exclusively shared, compared to those for which the values are detached from the ecological conditions.

*Proposition 2. Genetic materials of which ecological conditions are significant will be less likely to be shared exclusively without a third-party sharing restriction.*

### 3.1.2. Attributes of Actors

Sharing ultimately comes down to individual and interpersonal decisions about whether to share or not (Tucker 2009), although surrounding environments can influence individuals. Exclusive sharing may or may not occur depending on who has genetic materials and who wants the materials. As attributes of both material providers and receivers, their sectoral affiliation is examined in this dissertation.

Sectoral affiliation of individuals ranges from public sector to private sector. When it comes to research-related activities, universities play a significant role in a U.S. research community; university researchers produce more publications and set the rules and norms for the academic community (Anderson 2000). University researchers have primarily stood for a self-governing scientific community pursuing “best science.” As described by Merton (1942), the scientific community maintains its autonomy and legitimacy from society by adhering to its professional norms: universalism, communism, disinterestedness, and organized skepticism.[8] These norms have supported the "open science" institution advocating that researchers need to openly share their research tools – including genetic materials – with their peers for further verification and open academic discussion (Anderson 2000; Rodriguez 2005). Although an increasing tendency toward academic entrepreneurism or capitalism in American universities has limited the influence of an open science norm on university researchers in recent decades (Etzkowitz et al. 2000; Rodriguez 2005; Ziman 2000), it is still found that an open science norm remains influential without being replaced by the emerging academic capitalism in universities (Glenna et al. 2007; Shibayama 2012).

On the other hand, industry researchers are under the stronger influence of capitalism and commercialism (Aghion, Dewatripont, and Stein 2008; Kornhauser 1962; Sauermann and Stephan 2013). Aghion and his colleagues (2008) point out that, compared to university researchers, industry scientists have less autonomy and discretion in selecting their research agenda and are more directly guided by their organizational missions toward higher-payoff activities. Fundamental differences exist between university and industry research in terms of missions, reward structures, and dominant norms (Dasgupta and David 1994). Sauermann and Stephan (2013) summarize the different missions of the private sector as "commercial logic" which is contrary to academic logic. Commercial logic consists of norms toward the private appropriation of financial returns from knowledge and discovery, restrictions on information disclosure, and bureaucratic control over resources (Sauermann and Stephan 2013, 891). Under the institutional and organizational influence in the private sector, industry researchers can be discouraged from sharing their genetic materials with others outside their companies. Industrial researchers may become socialized with commercial logic and let go of academic missions once they join a company (Sauermann and Stephan 2013; Stern 2004). It is also possible that individuals who prefer higher payoffs

[8] According to Merton (1942), universalism means that science can be advanced based on an assessment on the quality of scientific work, which is separable from researchers' personal characteristics. Disinterestedness embodies the belief that science needs to be driven by neither political interests nor personal interests, but by pure scientific inquiry. Organized skepticism advocates that a scientific community as a whole needs to engaged in a positive criticism and public verification for scientific advance. For the public verification and scientific open discussion, communism advocates that scientific knowledge needs to be openly accessed and shared.

and private returns self-select into industry positions (Roach and Sauermann 2010). What seems to be obvious is, though, that industry scientists are more closely tied to commercial logic that can make material-sharing more exclusive.

At the same time, government scientists are the other important actors who use and exchange genetic resources in agricultural and food research. Historically, federal government laboratories, state and local government extension centers and inter-governmental research consortiums have played an important role in producing knowledge and inventions and disseminating them in agricultural research (Atkinson et al. 2003). Smith (1990) looks back to the establishment of Morrill Act (1862) and land grant universities and explains an exceptionally active role of government scientists in agricultural research (22). Government scientists were involved in the transfer of knowledge and technology in agriculture long before the US science policy shifted toward technology-transfer in the 1980s. Their role is still emphasized in the field (Atkinson et al. 2003; Eisenberg 2006). Aligned with the long-standing public missions regarding the transfer of knowledge/technology in agriculture, government scientists may have developed the stewardship toward open science and open sharing.

Since the mid-1990s, in response to the increasing capitalism and secrecy in science, government agencies have promoted sharing of data and research materials via publicly-funded projects and policy initiatives (Eisenberg 2006; Marshall 1999; Murray 2011; Piwowar 2011). These include data-sharing policies of the National Institute of Health and the National Academy of Science, and several government projects building open databases (e.g., National Center for Biotechnology Information and Germplasm Resource Information Network) or promoting the standardization of data structures (e.g., MIAME project). These initiatives are not limited to biomedicine research and have expanded to general scientific research (Hilgartner 1995). Under the missions of these initiatives, a substantive amount of genetic materials have been collected and stored in gene banks (e.g., the American Type Culture Collection) and made available for a broader range of users (Barton and Siebeck 1994; Byerlee and Fischer 2002; Stern 2004).

Given the commitments to open science that are stated in several public initiatives, government researchers may be more aware of and compliant with material-sharing policies. It is also possible that the missions of their agencies directly address the needs of public disclosure and sharing of research materials, which forces government scientists to share the materials with others. Or, the initiatives might have created pro-sharing norms and cultures within government agencies and motivated government scientists to proactively share their materials with others. Based on the existing stewardship advocating material-sharing in government agencies, it is reasonable to expect less exclusive sharing in government agencies.

All in all, it is posited that individuals – either material providers or material receivers – who are affiliated with industry are more likely to share genetic materials in an exclusive way compared to their counterparts in university and government.

*Hypothesis 1. Genetic materials sent to industry researchers will be more likely to be shared exclusively.*

*Hypothesis 2. Genetic materials obtained from industry sources will be more likely to be shared exclusively.*

### 3.1.3. Attributes of Sharing Process

Exclusive sharing is a sequential process in which two parties first share their materials and then decide whether to transfer the materials to a third party. The process by which two original parties share genetic materials can influence their subsequent decision on whether to share with others (Blumenthal et al. 2006; Piwowar 2011). Piwowar (2011) shows that those who had shared their research materials with someone tend to again share the materials with the others. More specifically, Blumenthal and his colleagues (2006) show that those who had experienced positive effects of material-sharing (e.g., creating collaborative relationships, producing publications, and getting alternative resources or non-monetary supports such as mentoring) were more likely to engage in subsequent sharing.

In general, previous literature identifies two important dimensions of sharing patterns: formalization (Mowery and Ziedonis 2007; Rodriguez 2005; Streitz and Bennett 2003) and reciprocity

(Haeussler 2011; Ipe 2003; Shibayama and Baba 2011). However, the earlier literature mostly focuses on material-sharing within a nation without considering cross-national flow of genetic materials. Since researchers seek genetic materials beyond their national borders (ten Kate 2002), this dissertation proposes considering national border effects in addition to the procedural attributes proposed in previous studies: formalization and reciprocity of material-sharing.

**(1) Cross-national Sharing**

Cross-national sharing entails substantial transaction costs given the geographic, socio-economic, and cultural differences that exist among scientists. National borders are believed to hinder the cross-national trade of biological materials due to the geographic distance and associated transaction costs (Chen 2004; Parsley and Wei 2001), regulatory constraints (Evans 2003; Turrini and van Ypersele 2010), and informal barriers resulting from different languages and cultures (Huchet-Bourdon and Cheptea 2011; Olper and Raimondi 2008).

Parsley and Wei (2001) examined transactions of specific commodities occurring in 96 cities in the US and Japan over 20 years and found the significant border effects on transaction rates. It reported that cross-national transactions between the US and Japan involved substantial transaction costs compared to cross-regional transactions within the nation. The substantial cross-national transaction costs were found to create segmented transaction patterns between the two countries. Parsley and Wei (2001) proposes that transaction costs are attributed to shipping costs associated with geographic distances as well as exchange rate variability caused by different currencies. Similarly, Chen (2004) found that geographic distance increased transaction costs and, in turn, creates spatial clustering in cross-national trades in European regions. Cross-national sharing of biological materials may bring about greater shipping costs and contamination risk than the transfer of manufactured products examined in the previous studies (Olper and Raimondi 2008). This is because living materials are easily contaminated or destroyed and they are subject to decay during a long delivery process without a proper handling.

Regulatory constraints imposed by various nations and international governments can create additional burdens. Multi-layered regulations stipulated in national, regional, and international tariffs, treaties, and agreements constrain individuals from accessing genetic materials and transferring the materials to others (Olper and Raimondi 2009). International agreements (e.g., the Agreement on Trade-Related Aspects of Intellectual Property Rights), and bilateral free trade agreements between nations add regulatory burdens in economic trades (Roffe 2008).

Regulatory burdens reside not only in market transactions. Global material-sharing can be hindered by various regulations on public health, national security, food safety, and environmental conservation (Black and Kireeva 2010; Roffe 2008; Santilli 2012). Quality standards, safety and health regulations, and quarantines are common regulatory instruments incorporated into international trade agreements and tariffs. The Convention on Biological Diversity (CBD) has also recommended that its member-countries adopt prior informed consent (PIC) or mutually agreed upon terms (MAT) in the global exchange of genetic materials.[9] Although these practices were advocated for fair and equitable use and exchange, these procedures can increase national barriers in the global exchange of genetic materials.

Border effects are found even in global research collaboration among scientists (Costello 1996; Engels and Ruschenburg 2008; Hoekman, Frenken, and Tijssen 2010). Costello (1996) challenges the utopian view of a scientific community as a borderless coproduction system; it argues that a global science community is highly localized and fragmented. Similarly, Hoekman and colleagues (2010) reported that geographic proximity has created significant variation in research collaboration in European areas, even after the European Union was institutionalized. Engels and colleague (2008) reported in a study of the United States and Japan that global collaboration is still restricted by national borders in that researchers encounters a difficulty in sharing ideas and research materials with foreign partners given the substantial time and costs required for global communication and collaboration. Specifically, differences in language, reward systems, political interests, and culture were found to be main barriers, which

[9] PIC requires that rights-holders (e.g., national governments, local and indigenous communities) be informed of and consent to the user obtaining the material, while MAT requires that the terms of access and use of the genetic resource be clearly stated, including provisions for benefit-sharing (Welch, Shin, and Long 2013).

generated uneven growth of global research collaboration across different regions (Engels and Ruschenburg 2008).

In sum, previous studies identify the negative effects of national borders on transaction rates, material transfer, and research collaboration. Given these border effects, Chen (2004) reported that domestic transactions tend to be five to twenty times greater than cross-national transactions. Based on previous findings, two possible scenarios of exclusive sharing can be developed, even though none of the research addresses how cross-national sharing would influence the subsequent material-transfer to a third party. First, material providers may not be willing to engage in subsequent material-sharing after realizing the substantial transaction costs required for cross-national sharing. Since it is difficult to track and monitor how genetic materials to be used from overseas, material providers may request not to transfer the materials to a third party in order to maintain their control over the materials. Second, material receivers may prefer material-withholding. Given the substantial transaction costs, not every researcher would be able to identify and obtain genetic materials from other countries. Those who had already obtained the materials may want to appreciate the competitive advantages stemming from a temporary monopoly of the foreign materials before passing them away to a third party. Although individuals' motivations of material-withholding differ in the two scenarios, both suggest that cross-national sharing can engender a subsequent material-withholding from a third party. In this sense, when genetic materials are obtained from abroad, they are posited to be more exclusively shared without a third-party transfer.

*Hypothesis 3. Genetic materials obtained from abroad will be more likely to be shared exclusively.*

### (2) Formalization of Material-sharing

Formalization of material-sharing refers to the degree to which the material-sharing process is documented as formal rules and enforcement instruments. This is similar to the concept, rule observation, that is proposed as one dimension of formalization in organization studies (Hage and Aiken 1967, 79).

Formalization takes place when rules and norms are specified in a written form (Pandey and Scott 2002; Pugh et al. 1968).

Formalization can either discourage or encourage scientists' sharing of genetic materials. On one hand, administrative burdens for documentation, formal communication and negotiation may increase transaction costs, thus discouraging scientists from engaging in another transaction to a third party. Stipulated procedures and obligations may also constrain scientists from freely passing on genetic materials obtained to other people. On the other hand, formalization can reduce future transaction costs and potential societal costs by making material-sharing processes more explicit and transparent. Zerbe and McCurdy (1999) assert that well-specified rights and obligations reduce confusion and potential disputes, which reduce transaction costs. Williamson (1979) also agrees that clear and specific information on ownership, responsibility and due procedures can reduce transaction costs, although he emphasizes the role of informal contracts as well as formal agreements. In sum, formalized agreements can enable both exclusive and inclusive sharing of genetic materials (Lei, Juneja, and Wright 2009; Streitz and Bennett 2003).

As a formal agreement on material-sharing, material transfer agreements (MTAs) have become institutionalized and are used in multiple contexts. MTAs were first devised by industry and gradually adopted by universities and government laboratories in the United States (Barton and Siebeck 1994; Lei, Juneja, and Wright 2009). Public agencies, such as the National Institutes of Health (NIH), the National Academy of Science, and the National Cancer Institute, have developed guidelines on material transfer agreements (e.g., a Uniform Biological Material Transfer Agreement, UBMTA) and promoted the formalization of the material-sharing process. Agricultural research centers and gene banks at the domestic and international levels have also adopted a policy to recommend the use of MTAs (e.g., Standardized Material Transfer Agreement (SMTA) in the International Treaty on Plant Genetic Resources for Food and Agriculture) for multiple purposes.

Literally, MTAs are contractual agreements among more than two parties. As a bilateral or multilateral contract, MTAs are used to enforce individual parties' compliance. However, MTAs are not based on specific legal statues or regulations. Instead, individuals have discretion in setting the terms of agreement and refining them to meet their specific needs (Barton and Siebeck 1994, 12). Given their flexible applications, MTAs have been used not only for setting sharing restrictions but also for mandating open sharing.

In a competitive and commercialized research environment, MTAs have often been used by industry researchers when they pursue confidential co-production with partners outside their organizations (Barton and Siebeck 1994). Compared to patent systems that require ownership specification over specific inventions, MTAs are believed to better serve researchers' needs to develop a confidential research cooperation even before the scientific or commercial value of the materials is discovered (Barton and Siebeck 1994). Researchers use MTAs in pre-competitive research or at an early stage of development in order to minimize potential risks associated with material-sharing, such as a breach of confidential genetic information, a loss of control over the stock and flow of their materials, and the socio-economic costs of legal disputes on potential property rights (Ghijsen 2009).

In this context, MTAs tend to include restrictions on a third party transfer and commercial use of genetic materials. Rights and obligations associated with property rights, such as patenting and licensing, are also specified in MTAs (Barton and Siebeck 1994; Lei, Juneja, and Wright 2009), although rights over unexpected discoveries might not be fully spelled out. Claims for reach-through rights are also included in MTAs when the future value of genetic materials and subsequent inventions are not fully appreciated but are expected to be high. Reach-through rights grant an original inventor relatively long-term intellectual property rights over a series of improvements, modifications and new inventions that are rooted in an original invention (Walsh, Cohen, and Cho 2007). MTAs have gradually been adopted not only by industry researchers but also by university and government researchers as a way to ensure confidential use of genetic materials as commercialization in American universities and government agencies has increased (Barton and Siebeck 1994; Mowery and Ziedonis 2007).

However, MTAs have also been used to ensure unrestricted access to genetic materials. Government research laboratories, such as national agricultural research centers, grant material-recipients a right to freely use their genetic materials via MTAs (Barton and Siebeck 1994; Lei, Juneja, and Wright 2009). MTAs are also used to specify material recipients' obligations to make the materials they receive available in a public domain (Hilgartner 1995; McCain 1995; Stern 2004). Public agricultural research centers, gene banks, and bio-banks began to use MTAs in order to mandate free material-sharing (Barton and Siebeck 1994; Halewood and Nnadozie 2008). MTAs have also been used in several national research programs and international initiatives to clarify the rights of material-providers and the obligation of material-receivers so that the benefits from the use of the materials can be fairly distributed to both material-receivers and material-providers (Barton and Siebeck 1994). In this context, MTAs tend to include provisions that restrict material-withholding and exclusive rights, such as reach-though rights, over the materials.

Given the mixed uses of MTAs, it is challenging to identify the overall independent effect of MTAs on exclusive sharing. This might be the reason why some previous empirical studies do not find a significant association between MTAs and material-sharing (Mowery and Ziedonis 2007; Rodriguez et al. 2007).

Nevertheless, much of the literature reports that MTAs more than often include restrictions on use and exchange of genetic materials (Blumenthal et al. 2006; Lei, Juneja, and Wright 2009; Walsh, Cho, and Cohen 2005; Walsh, Cohen, and Cho 2007). Lei and colleagues (2009) examined the role of MTAs in agricultural biology and found that MTAs were associated with a significant delay in material transfer. It reported that it took four to six months for agricultural scientists to obtain genetic materials from partners when they used MTAs. For this reason, university researchers were often found not to comply with university policy mandating the use of MTAs; only one third of material-transfer made in land grant universities were found to have MTAs (Lei, Juneja, and Wright 2009). On the other hand, MTAs seem to be more commonly used by industry actors. Walsh and colleagues (2007) show that, in biomedical research, 70% of industry researchers used MTAs, whereas only 35% of university researchers did so. It was also reported that 38 % of MTAs included reach-through rights agreements restricting access to genetic materials for further improvement. Despite public initiatives promoting material-sharing via

MTAs, the negative effects of MTAs on material-sharing were found even in universities (Walsh, Cohen, and Cho 2007); 29 % of MTAs made by university researchers were found to include reach-through rights.

All in all, although MTAs have been devised for both open as well as exclusive sharing, empirical studies indicate that MTAs are more intensively used for exclusive sharing. Therefore, it is posited that the formalized sharing process accompanying MTAs is positively associated with exclusive sharing.

*Hypothesis 4. Genetic materials that come with a material transfer agreement will be more likely to be shared exclusively.*

**(3) Reciprocity of Material-sharing**

Reciprocity of material-sharing implies that a material recipient is obliged to compensate a provider for the given materials by giving something back (Haeussler 2011, 108). Reciprocity is considered as a critical factor motivating exchange and sharing behavior (Das and Teng 2002; Emerson 1976; Homans 1958). In order to make an exchange fair or seemingly fair, recipients are expected to offer providers goods or services that have more or less equivalent values to the one they received. Recent game theory further specifies reciprocity as a behavioral response to perceived kindness (Rabin 1993). Once player *i* perceives that player *j* makes a kind offer, player *i* is likely to engage in “other-regarding behaviors” by making another kind offer to player *j*. This is called a reciprocity game, which generally supports that one’s kind offer motivates other players to be kind (Dufwenberg and Kirchsteiger 2004; Falk and Fischbacher 2006).

Perceived or expected reciprocity between two parties motivate them to share their materials with each other. Molm (2003) argues that perceived reciprocity matters more than the exact value of the benefits in motivating individuals to engage in social exchange. Shibayama and Baba (2011) show that if scientists anticipate that others will provide benefits in return – especially non-monetary benefits – they will be less likely to deny a request for research materials. Furthermore, it is reported that the expectation of reciprocal benefits in an ongoing relationship significantly decreases denial rates and helps scientists gain access to research materials.

The positive effects of reciprocity can be found not only in bilateral sharing but also in more open public sharing. Gouldner (1960) classifies "reciprocity" motivating social exchange into three types: reciprocity as 1) a pattern of mutually contingent exchanges of rewards between two parties, 2) the existence of expected, but not mandatory, rewards among more than two parties, and 3) the generalized social norm of reciprocity at the societal level (Gouldner 1960, 161). Accordingly, not only negotiated reciprocity between two parties but also the generalized norm of reciprocity motivate individuals to engage in material-sharing. It continues that individuals tend to provide their resources to others even when they do not foresee immediate and tangible rewards in response to their offers if a society as a whole holds a norm of reciprocity and develops a moral code on reciprocal returns (Gouldner 1960). If most societal members hold reciprocity as one of the universal principles, generous offers are more likely to be paid back even though reciprocal returns are not directly discussed and negotiated among individuals. In this case, individuals may feel less risky when they make a generous offer because the societal norm of reciprocity can serve to discourage others' opportunistic behaviors.

Social capital theorists conceptualize a norm of reciprocity as one type of social capital, which can promote not only direct mutual sharing but also indirect generalized sharing with the public (Coleman 1988; Haeussler 2011; Nahapiet and Ghoshal 1998). They assert that reciprocity expected and realized at the societal level enhances trust among societal members, which can encourage members to share resources even with unknown third parties. Contemporary game theorists also support the idea that reciprocity between two parties can motivate them to engage in subsequent cooperation with a third party in various scenarios (Nowak and Sigmund 2005). Under the headings, "indirect reciprocity", "generalized reciprocity", or "third party altruism," several studies show that individuals who had reciprocal relationships with one party are more likely to cooperate with a third party (Berger 2011; Boyd and Richerson 1989; Nowak and Sigmund 2005; Ostrom 2000); these phenomena are associated with multiple underlying factors, such as a sense of community, social reputation, and informal rules made throughout a series of repeated social exchanges over time.

When it comes to material-sharing among scientists, Haeussler (2011) examined the role of reciprocity in both university and industry sectors. It found that not only the expected reciprocity among two researchers but also the degree to which a research community adheres to a norm of reciprocity influenced material-sharing among scientists. In addition, Blumenthal and colleagues (Blumenthal et al. 2006) reported that positive sharing experiences led to greater willingness to share resources with a third-party in the field of biomedical research. If individuals experienced reciprocal and equitable sharing, they were less likely to concern about "being scooped" by other researchers and more willing to share their genetic materials with the others.

Based on theoretical and empirical research, reciprocity is expected to have a positive association with subsequent transfer to a third party. In other words, genetic materials obtained based on a reciprocal relationship between a material provider and a material recipient is posited to be less exclusively shared without a third-party sharing restriction.

*Proposition 3. Genetic materials obtained based on a reciprocal relationship will be less likely shared exclusively without a third-party sharing restriction.*

### 3.1.4. Attributes of Demand Environment

The demand environment surrounding both material providers and receivers has been extensively studied as a determinant of exclusive sharing (Campbell et al. 2002; Eisenberg 2006; Hagstrom 1974; Hong and Walsh 2009; Murray and Stern 2007; Walsh, Cohen, and Cho 2007; Walsh and Hong 2003). This literature identifies two major attributes of demand environments that are associated with scientists' sharing and withholding behaviors: 1) scientific competition and 2) commercialization.

Scientific competition refers to the degree to which scientific production is based on an individual goal that cannot be shared with others (Hagstrom 1974; McCain 1991). Scholars in the sociology of science acknowledge that competition for recognition and conflict over priority are inherently institutionalized in scientific production (Hagstrom 1974; Hong and Walsh 2009; McCain 1991; Mitroff 1974). Even Merton (Merton 1942, 1957), who proclaims communal norms in science, admits that the great emphasis on “original and significant discoveries” may increase scientific competition. In a system where recognition is granted only to the first original discovery, scientists are forced to compete with others in order to be the first. The greater the number of scientists involved in the discovery of the same subject matter, the more competitive the environment and the lower the chance of an individual scientist being the first. In a competitive field, scientists who disclose research ideas and materials in the early stages of informal meetings may be more likely to be defeated by their competitors who publish a paper using the same ideas, data or materials before them (Hagstrom 1974). As a result, the greater the competition, the more scientists withhold their research materials and protect their lead time advantage instead of freely sharing their ideas and materials with competing peers (Hong and Walsh 2009; Merton 1957; Mitroff 1974). In this regard, scientific competition has been associated with scientists’ secretive behavior, data withholding, and denial of material transfer requests in the field (Hong and Walsh 2009; McCain 1991; Sullivan 1975; Walsh and Hong 2003).

Similarly, commercialization of the field has been increasingly cited as a major barrier for material-sharing in recent decades (Blumenthal et al. 1997; Campbell et al. 2002; Murdoch and Caulfield 2009; Rosenberg 1996; Thursby and Thursby 2003; Walsh, Cohen, and Cho 2007). Along with academic capitalism or commercialism (Aghion, Dewatripont, and Stein 2008; Kornhauser 1962; Sauermann and Stephan 2013), property rights over scientific discovery and inventions have expanded not only for private sector researchers but also for public sector researchers. Privatizing the returns from individual discoveries or inventions through patents have been increasingly prioritized across sectors and disciplines (Cohen, Nelson, and Walsh 2000; Stephan 1996). Hong and Walsh (2009) show that commercialization in science has substantially expanded even in universities. Interactions between university and industry have increased within research consortia, researcher exchange programs, joint-ventures and other types of research and development collaboration. Along with commercialization, Hong and Walsh (2009) show that secrecy has increased. It is found that the more commercialized the field is, the more reluctant scientists are to talk with other colleagues about their own research.

In line with this result, several studies report that commercialization is negatively associated with scientists' sharing of research materials (Blumenthal et al. 1997; Blumenthal et al. 2006; Campbell et al. 2002; McCain 1991; Murdoch and Caulfield 2009; Walsh, Cohen, and Cho 2007). Blumenthal and his colleagues (1997; 2006) report that, in the life sciences, scientists' refusal to share their research materials is associated with a greater tendency towards commercialization. Researchers in genetics in which patenting became prevalent were more likely to withhold research materials from others than researchers in other life science disciplines (Blumenthal et al. 2006). Commercial activities such as patenting, licensing and start-ups were also found to directly influence individuals' material-withholding behavior (Blumenthal et al. 2006; Campbell et al. 2002; Lei, Juneja, and Wright 2009). Industry sponsorship was also found to constrain researchers from freely share research materials with colleagues (Blumenthal et al. 1997; Evans 2010; Hong and Walsh 2009). According to Campbell et al. (2002), about 10 percent of requests for research information, materials, and data that had been made between life scientists were rejected. This tendency to withhold research materials seems to be intensified over time. In a follow-up study to Campbell et al. (2002), Walsh et al. (2005) found that the denial rate went up from 10 to 18 percent in the field of life sciences. Both reports indicate that the request denials are associated with commercial activities and industry funding.

Given the association between commercialization and material-withholding in previous studies, it is hypothesized that genetic materials used in a commercialized research environment will be more likely to be withheld from a third party and more exclusively shared.

*Proposition 4. Genetic materials used in a commercialized research environment will be more likely to be shared exclusively.*

## <u>3.2. Consequences of Exclusive Sharing on Research Outcomes</u>

Does exclusive sharing of genetic materials matters for research outcomes? Basically, it has been widely accepted that free and open sharing of research materials is vital to scientific advances (Eisenberg

2006; Heller and Eisenberg 1998; Marshall 1998; Merton 1942; Nelson 2004; Polanyi 1962). Open disclosure of research findings and sharing of research materials enables scientists to check and validate prior research, avoid redundant work, explore unanswered questions, learn from each other, and eventually advance science in a collective way (Merton 1942; Polanyi 1962). In agricultural research, crossing and testing plant varieties in different agro-ecological environments has been regarded to advance modern agricultural science at large (Binenbaum, Pardey, and Wright 2001).

Exclusive sharing among selected members or material withholding can hamper others' research activities and delay others' publications. (Blumenthal et al. 1997; Campbell et al. 2002). Campbell et al. (2002) show that 28 percent of scientists reported difficulty when replicating published results because of another academic scientist's unwillingness to share information, data or research materials, including genetic materials. Moreover, anti-commons theory (Biddle 2012; Heller and Eisenberg 1998) asserts that exclusive rights in science bring about under-utilization of research materials; it supports the rationale of public initiatives that mandate open disclosure of research materials and findings (Marshall 1998, 1999; McCain 1995; Stern 2004). From this perspective, open sharing and free flow of genetic materials is regarded as a prerequisite to promoting science.

Nonetheless, the negative effects of exclusive sharing on research outcomes might not be obvious if one only focuses on the members of a research project that has already obtained genetic materials but has not shared materials with others. In fact, individual advantages stemming from material withholding and exclusive sharing have been largely acknowledged (Haas and Park 2010; Mitroff 1974; Tucker 2009). Individual researchers can fully appreciate the scientific and commercial value of genetic materials while withholding those materials from other competitors. In fact, scientists are often found to develop a confidential cooperative research arrangement in order to appreciate the advantages of temporary monopoly within the research team before publicizing the materials (Blumenthal et al. 2006; Campbell et al. 2002; Hong and Walsh 2009; Walsh, Cohen, and Cho 2007).

Several scholars (Haas and Park 2010; Mitroff 1974; Tucker 2009), including Merton (1968), identify the existence of tangible private returns that constrain scientists' commitment to traditional open science norms. Existing tensions between private returns and public benefits are described as Prisoner's Dilemma (Haeussler et al. 2009). If a researcher shares her materials with others, she may lose a scientific lead by letting others to make a scientific discovery before she does. The potential risks and costs of material-giveaway discourage her from initiating material-sharing even though she is aware of a possibility to get a greater payoff when she successfully elicits cooperation from others.

Again, there are vital tensions in science regarding exclusive sharing (Chubin 1985; Haeussler et al. 2009; Mitroff 1974; Tucker 2009). At the field level, exclusive sharing is thought to prevent the circulation of ideas and research materials, deter the cross-validation of research methods and findings, and eventually limit scientific progress. On the other hand, at the individual level, scientists may see tangible and immediate returns when they exclude others and withhold materials.

"If tensions regarding exclusive sharing exist in science, then do these tensions accrue in the same way as for publications and intellectual property outcomes?", and "how do these tensions influence the likelihood of publications as well as intellectual property outcomes?" In response to these questions, recent studies on the role of collaboration in producing publications and intellectual property outcomes are reviewed and hypotheses on the effects of exclusive sharing are further developed. Recent studies on co-publication and co-invention (Ducor 2000; Meyer and Bhattacharya 2004) suggest that unrestricted open collaboration with a large number of partners can influence research outcomes in different ways, depending on the type of research outcomes (i.e., publications versus intellectual property outcomes such as patents and licenses). The benefits of material-sharing with publications may differ from those with intellectual property outcomes.

Regarding intellectual property outcomes, the benefits of exclusive sharing can be obvious. This is because patenting requires scientists to specify utilities and practical applications of an invention in definite terms (Meyer and Bhattacharya 2004). The skilled artisanship of an individual can be more useful than generalizable knowledge obtained from diverse collaborators for achieving intellectual property-related outcomes.[10] Hence, having fewer collaborators might not hinder scientists from specifying particular practical applications and pursue intellectual property outcomes.[11] At the same time, individual returns from exclusive sharing can be more apparent when scientists pursue intellectual property outcomes. This is because exclusive access to genetic materials helps scientists maintain control over research activities using genetic materials and fully benefit from the industrial and commercial values of the materials by themselves.

On the other hand, the benefits of exclusive sharing on publications might not be apparent. Instead, publications can be more readily achieved by open sharing with a wide range of collaborators given the identified positive effects of research collaboration on publications (Lee and Bozeman 2005). When scientists share genetic materials as a means of research collaboration (Shibayama and Baba 2011), they may take an advantage of the collaboration for their publications. The identified collaboration advantages include increased work efficiency based on division of labor, expanded research scopes and an identification of new publishing opportunities, intellectual inspirations and learning from collaborators, and companionship with peers in a field of research (Lee and Bozeman 2005). In fact, it is reported that the number of publications increase as the number of collaborators increases (Lee and Bozeman 2005). If scientists do not allow a third-party transfer, they may limit their ability to expand their research collaboration with possible coauthors outside the project teams.

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[10] In addition, the degree to which individuals are constrained by institutional pressure on sharing can differ depending on the types of research outcomes. Meyer and Bhattacharya (2004) report that coauthors of a scientist are interconnected with each other since most of them work in the same field of research, which is contrary to the network of co-inventors. Co-inventors of a scientist are not interconnected with each other, but instead, tend to have a single dyadic relation with the scientist (Meyer and Bhattacharya 2004). The loose network in patenting activities may allow scientists to pursue their own private interests by withholding genetic materials, whereas relatively dense and interconnected networks in publication activities may constrain scientists from acting against the field norm or general expectations from peers advocating open sharing of research materials. The way in which benefits are distributed among collaborators also differ depending on the types of research outcomes. Having one more collaborator in patenting or licensing can reduce the monetary returns and royalties of each individual, whereas having one more collaborator in publishing might not substantially limit individual returns to each author (Ducor 2000). Having more collaborators in publications may increase the individual returns for each author by increasing citation rates and visibility of the research.

[11] In fact, the number of co-inventors for a particular invention are found to be much fewer than the number of co-authors for particular knowledge that is associated with a particular invention (Ducor 2000).

For these reasons specified above, it is posited that exclusive sharing of genetic materials is negatively associated with the likelihood of producing publications, and positively associated with the likelihood of having intellectual property outcomes.

*Hypothesis 5. A research project in which genetic materials are exclusively shared will be less likely to produce journal publications.*

*Hypothesis 6. A research project in which genetic materials are exclusively shared will be more likely to produce intellectual property-related outcomes.*

## 3.3. Summary

In a nutshell, whether genetic materials are exclusively shared or not is explained by four major attributes: the attributes of 1) shared objects (i.e., genetic materials), 2) the sharing actors, 3) the sharing process, and 4) the demand environment in which genetic materials are shared. Figure 4 summarizes the conceptual model developed in this dissertation.

As attributes of shared objects, greater market and non-market values of genetic materials are expected to increase the likelihood that scientists share the materials exclusively, whereas the significance of ecological conditions is expected to decrease the likelihood of exclusive sharing. As attributes of the sharing process, cross-national sharing and formality are expected to increase the likelihood of exclusive sharing, whereas reciprocal relationships between materials providers and receivers is expected to decrease the exclusiveness in material-sharing. In terms of actor attributes, sector affiliation is posited to influence exclusive sharing. Compared to university and government researchers, industry researchers are expected to be more likely to engage in exclusive sharing without transferring genetic materials to a third party. Lastly, in terms of the attributes of research environments, both scientific competition and commercialization are posited to increase the likelihood of exclusive sharing.

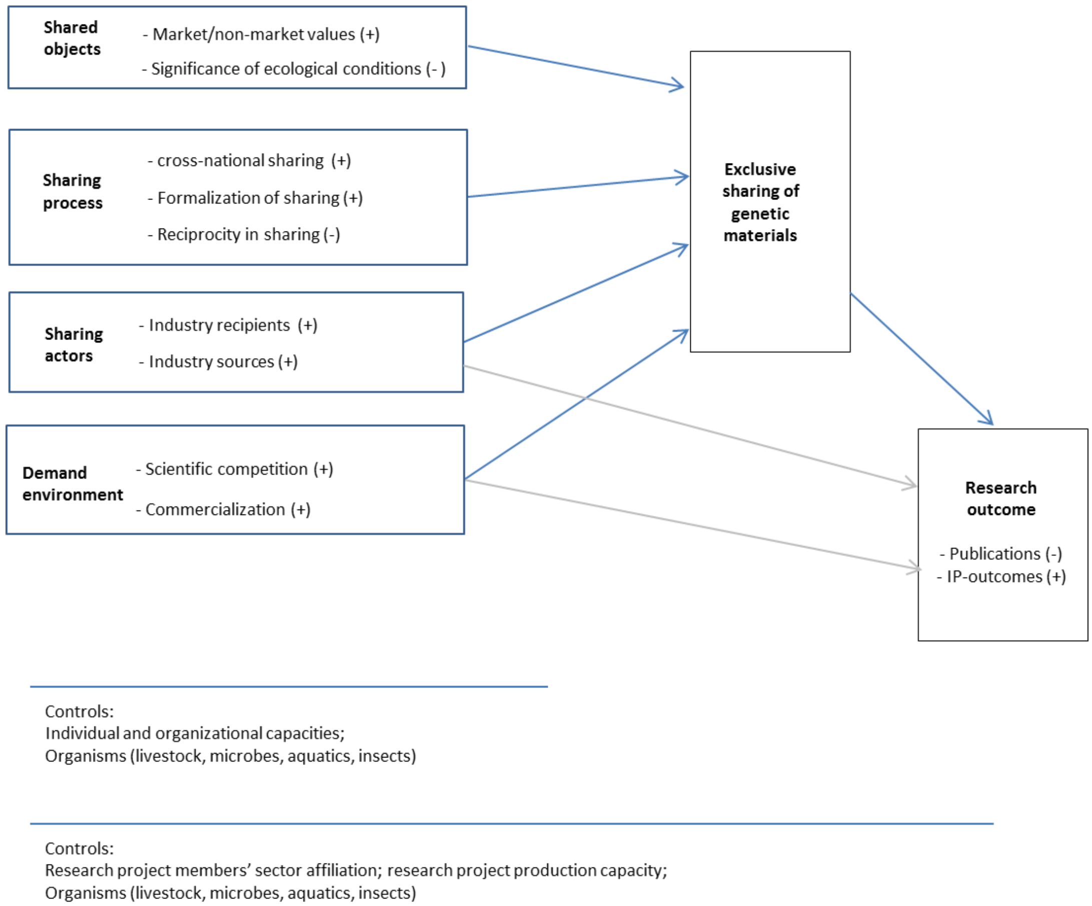


Figure 4. Conceptual Model

At the same time, exclusive sharing predicted by socio-ecological factors is hypothesized to influence research outcomes. Exclusive sharing is expected to decrease the likelihood of producing publications and increase the likelihood of producing intellectual property outcomes. In the second model predicting research outcomes, industry affiliation of material recipients and a commercialized research environment are controlled for. This is because both industry employment and commercialized research environment are reported to increase the likelihood of intellectual property outcomes (Agrawal 2001; Sauermann and Stephan 2013; Shane 2000; Thursby and Thursby 2002), while decreasing the likelihood of publications (Blumenthal et al. 1996; Buenstorf 2009; Campbell et al. 2002).

# 4. DATA AND METHODS

The theoretical framework developed in the previous chapter was empirically tested using data from two national surveys of agricultural scientists in the U.S. Quantitative research methods were used to investigate the sequential process through which socio-ecological factors influence scientists' exclusive sharing and eventually influence certain research outcomes. Since the survey data had missing items, additional investigations on item-nonresponses were conducted. This chapter specifies data, methods and measures used in the empirical analyses. An empirical model is presented in the end of the chapter.

## 4.1. Data

### 4.1.1. Survey Sample and Data Collection

Data come from a 2010 survey of government and university researchers and an almost identical 2011 survey of company researchers. The sample frames of both surveys included the U.S. national population of researchers who use non-plant genetic resources (i.e., microbes, livestock, aquatics, and insects) for food and agricultural research.

For the 2010 survey, university and government researchers were sampled primarily based on online information on organizational members retrieved from organizational websites. First, a list of 201 universities was constructed by merging the list of the Carnegie classified research intensive and research universities and the list of veterinary universities designated by the Association of American Veterinary Medical Colleges as of 2010. Second, a list of government agencies was drawn from the Agricultural Research Services (ARS) under the U.S. Department of Agriculture. They include 262 subunits of ARS that are located across the nation.

Using organism-specific keywords devised by experts in the field during the pre-interview stage in 2010, a research team sampled university and government researchers who worked on any one of eight organisms representing four areas: microbes (*listeria*, *fusarium*, porcine reproductive and respiratory syndrome virus), livestock (cattle), insects (honey bees), and aquatics (rainbow trout, hybrid striped bass, white-leg shrimp). These keywords were searched on each department's website within 201 universities and organizational websites of the 262 subunits in the Agricultural Research Services (ARS). Individual researchers who had any research projects, government reports, presentations and publications associated with one of the eight organisms were sampled. A total of 1401 researchers were identified from university and government websites and invited to the 2010 survey.

Using a snowball sampling design, all the survey respondents were asked to nominate other researchers in the government or university setting who would be able to respond to the survey. In total, 171 individuals were nominated during the survey; but 137 individuals were found to have already been invited to the survey or determined to be ineligible cases mainly because they were retired or not working in the US. Hence, only 34 individuals were additionally invited during the survey. In total, 1435 researchers were invited to the survey: 521 from federal government and 914 from universities. Table II briefly summarizes the sampling process done before and during the 2010 survey.

The 2010 survey was administered between November 5, 2010 and February 7, 2011. Based on a screening from the survey's first question in addition to email communication from invited researchers, 377 were determined to be ineligible as they had not actually used the genetic resources, even though their research profiles included organism-specific keywords. Given the information on the proportion of eligible samples out of the total sample (e=1058/1435), the eligibility rate of the sample was calculated and used to adjust the sample size (Table IV). Out of the adjusted sample size of 921, 411 researchers completed the survey, so the final response rate was 44.6% (AAPOR RR4).[12]

[12] American Association for Public Opinion Research's *[*AAPOR*]* response rate 4 (RR4) is a reasonable way to calculate a response rate (Smith 2009). It assumes that unknown cases are neither 100% eligible nor 100% ineligible; it considers that unknown samples have the same eligibility rate (e) as the one of the known samples. So it adjusts a sample size, particularly the size of unknown samples, by multiplying the number of unknown samples by the known eligibility rate (e). Hence, the adjusted sample includes potentially eligible unknown samples as well as all the other types: completes, partial completes, refusals, delivery failures, and others. AAPOR RR4 is essentially the number of complete and partially complete responses divided by the adjusted total sample size (The American Association for Public Opinion Research 2011).

TABLE II. SURVEY SAMPLE OF THE 2010 SURVEY

| | N |
|---|---|
| INITIAL SAMPLE | |
| **University researchers**: searched in 201 US Research intensive and research universities and veterinary medical schools | 513 |
| **Government researchers**: searched in 262 subunits of the Agricultural Research Services, US Department of Agriculture | 888 |
| Researchers invited from the beginning of the survey | 1401 |
| SNOWBALL SAMPLE | |
| Researchers nominated by the respondents during the survey | 171 |
| Researchers already included in the initial sample or ineligible samples | 137 |
| Researchers invited during the survey | 34 |
| TOTAL INVITES | 1435 |

For the 2011 survey, company researchers were sampled from an integrated list from multiple sources. The sources of information included (1) membership lists of academic and commercial associations related to eight organisms, (2) author information of the publications that include the organism-specific keywords in the Web of Science, and (3) information on companies and company researchers named by survey respondents of the 2010 survey and interviewees of the 2010 pre-interview. There were significant overlaps among these three sources of information, although membership lists provided the broadest coverage of this population. Specifically, membership lists comprised company and non-profit workers who were affiliated with any one of 16 different national-level associations; they included the American Society for Microbiology (Agriculture/Veterinary and Food Product sections), American Phytopahtological Society (APS), the National Association of Animal Breeders, Beef Improvement Federation, the World Aquaculture Society (U.S. company researchers who presented in the 2009 or 2010 American Aquaculture conferences), the Striped Bass Growers Association, the American Beekeeping Federation (company members), and the American Association of Professional Apiculturists (AAPA).

A total of 1048 researchers were identified as company researchers in the field of eight organisms. Using a snowball sampling design, survey respondents were also asked to nominate other company researchers who would be eligible for the survey. In total, 20 individuals were nominated during the survey; eight cases were duplicates from the original sample or ineligible cases so 12 were invited. Hence, a total of 1060 researchers were invited to the 2011 survey as company researchers (Table III).

TABLE III. SURVEY SAMPLE OF THE 2011 SURVEY

| | N |
|---|---|
| INITIAL SAMPLE | |
| **Company researchers**: searched via<br>(1) membership lists of academic and commercial associations<br>(2) author information from the Web of Science<br>(3) nominated by the 2010 survey respondents or interviewees | 1048 |
| Researchers invited from the beginning of the survey | 1048 |
| SNOWBALL SAMPLE | |
| Researchers nominated by the respondents during the survey | 20 |
| Researchers already included in the initial sample or ineligible samples | 8 |
| Researchers invited during the survey | 12 |
| TOTAL INVITES | 1060 |

Based on the screening from the survey's first question as well as email communication from invited researchers, 202 researchers were determined to be ineligible as they had not actually used the genetic resources although they worked on the relevant subject. Based on the identified eligibility rate (e) of the sample, the size of unknown cases was adjusted (Table IV). In total, 159 out of 748 researchers who potentially used genetic materials completed the survey; the final response rate was 21.3% (APPOR RR4). The low response rate of the 2011 survey is not surprising because previous research also found that the response rates of company survey range from 20% to 25% (Rose, Sidle, and Griffith 2007). Company employees are also reported to be more reluctant to participate in a survey given an organizational policy restricting the disclosure of company information (Baruch and Holtom 2008). Therefore, the response rate of the 2011 is low but not unusual case as a company survey.[13]

Nonetheless, it is challenging to assess the coverage errors and unit nonresponse bias present in the survey data because of the lack of understanding on a specific population of interest. There exists no comprehensive assessment on the population of researchers who use one of the eight non-plant genetic materials for research in the United States.

The only available proxy indicator would be the degree in which an initial sample frame was overlapped with the one of nominees later named during the survey. Similar to capture-recapture sampling, the degree to which initial samples were again nominated during the survey may indirectly indicate the size of total population and the coverage of the sample. For the 2010 survey of university and government researchers, 171 researchers were nominated as potential candidates of genetic material-users during the survey; 116 out of them were found to have already been invited to the survey.[14] This may indicate that the initial sample frame of university and government researchers was quite comprehensive to cover a target population. Nonetheless, this cannot be over-interpreted since the ration of initial samples nominated divided by the total number of nominees (116 out of 171) was simply drawn from a single-trial, which cannot be equivalent to the figures drawn from capture-recapture sampling.

For the 2011 survey of company researchers, very few people (i.e., 20 researchers) were nominated and only one individual was found in the initial sample frame.[15] Given the limited number of nominees, it is hasty to draw any conclusion on the coverage of company survey sample. In general, the coverage of this survey sample used in this study is largely unknown despite a proxy indicator from

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[13] Furthermore, the response rate is an indicator neither of data quality nor of data representativeness (Baruch and Holtom 2008). Additional investigation is required to understand data quality as well as representativeness beyond a report of response rate, because it is possible to obtain high quality data even with a low response rate.

[14] As shown in Table II, only 34 individuals out of 171 nominees were additional invited to the sample. Out of 137 individuals who were not invited to the survey, 116 individuals were the one who had been already invited to the survey whereas 21 were determined to be not eligible because of their work status (e.g., retired, or working outside the US) and research specialty (e.g., research not related to one of the eight organisms) were not met the criteria of sample selection in this study.

[15] As shown in Table III, 12 out of 20 nominees were invited during the 2011 survey. The rest of nominees who were not invited include 7 individuals whose research specialty and work status were not met the criteria of sample selection in this study and determined to be ineligible and 1 individual who had been already invited to the survey.

snowball sampling. Therefore, it needs to be acknowledged that the findings from this study cannot be generalized to a target population.

Additional screening was done for the 2011 survey data because a small proportion of respondents were found to work with plant genetic resources that was not taken into consideration in the 2010 survey. After removing the responses of plant researchers, 135 cases from the 2011 survey were merged with the 2010 survey data. In total, the merged dataset includes 546 observations: 411 observations from the 2010 survey and 135 from the 2011 survey. Table IV summarizes the changes in sample size made during the data collection and cleaning phases.

TABLE IV. SAMPLE SIZES AND RESPONSE RATES

| | 2010 Survey Data | 2011 Survey Data | Merged Data |
|---|---|---|---|
| **Data Collection Phase** | | | |
| Invitees | 1435 | 1060 | |
| Eligibles | 1058 | 858 | |
| Completes | 365 | 140 | |
| Partial completes | 46 | 19 | |
| Break-offs | 20 | 18 | |
| Refusals | 79 | 32 | |
| Out of office | 7 | - | |
| Delivery failure | 20 | 74 | |
| Unknown | 521 | 575 | |
| - Eligibility rate (e) | 0.737 | 0.809 | |
| - e*Unknown | 384 | 465 | |
| Adjusted Sample Size [a] | 921 | 748 | |
| Completes + partial completes | 411 | 159 | |
| Response Rates (AAPOR 4) | 44.6% | 21.3% | |
| **Data Cleaning Phase** | | | |
| Completes w/o plant researchers | 411 | 135 | 546 |
| Completes with project data | 282 individuals (715 projects) | 85 individuals (258 projects) | 367 individuals (973 projects) |

[a] The adjusted sample size is the sum of all the response categories when a unknown category is adjusted based on the known proportion of eligible samples out of the total sample.

Both surveys employed web survey instruments with the assistance of mixed-mode contacts (e.g., mail invitations/reminders and reminder calls). Survey questionnaires were almost identical across the surveys except for a few sector-specific questions. In addition to individual-level data on exchange patterns and practices, attitudes, and demographics, the survey collected project-level data from respondents who had active projects regarding genetic materials. Project-level data were collected by first asking researchers to name current research projects they worked on during the last two years. In detail, three open-ended questions (i.e., name-generator questions) were used to collect information on the project titles (Table  V).

For the 2010 survey of government and university researchers, three questions on projects funded by government and industry and independent projects without external funding were used to collect open-ended responses on project names. For the 2011 survey of company researchers, the three questions were slightly revised and asked about projects funded by government, other companies and own company.

TABLE V. SURVEY QUESTIONS USED FOR COLLECTING PROJECT-LEVEL DATA

| | Names of open-ended responses filled in name generator questions |
|---|---|
| **[All the name-generator questions used]** | |
| **In the 2010 survey of government and university researchers** | |
| Please name up to five projects that used genetic materials that you worked on in the last two years and were funded (fully or partially) by governments, universities or foundations. | PJCT1-5 |
| Please name up to five other projects using genetic resources that you worked on in the last two years that were fully or partially funded by the private sector. | PJCT6-10 |
| Thinking about projects that you worked on over the last two years that were not funded by government(s), foundation(s) or the private sector, please name up to five other projects (not yet named) that used genetic resources and were non-funded. | PJCT11-15 |
| **In the 2011 survey of company researchers** | |
| Please name up to five projects that used genetic resources that you worked on in the last two years and were funded (fully or partially) by governments, universities or foundations. | PJCT1-5 |
| Thinking about projects that you worked on in the last two years that were not funded by government(s)or foundation(s), please name up to five other projects (not yet named) that used genetic resources and were entirely funded by your own company | PJCT6-10 |
| Please name up to five other projects (not yet named) using genetic resources that you worked on in the last two years that used and were fully or partially funded by other companies or industry associations. | PJCT11-15 |

**[An example of name-interpreter questions used in both surveys]**

For the Projects you named, please indicate whether any of your collaborators are primarily affiliated with a:

| | University or college | Government organization or agency | Private industry including trade associations | Non-profit (not government or university) |
|---|---|---|---|---|
| [PJCT1] | ○ | ○ | ○ | ○ |
| [PJCT2] | ○ | ○ | ○ | ○ |
| … | | | | |
| [PJCT6] | ○ | ○ | ○ | ○ |
| … | | | | |
| [PJCT14] | ○ | ○ | ○ | ○ |
| [PJCT15] | ○ | ○ | ○ | ○ |

For each question, respondents were able to name up to five project titles. Therefore, each person could name at most 15 projects in total from a technical point of view. However, the actual maximum number of projects named by one individual was 13. In addition, over 92% of respondents named at most five projects. On average, one respondent reported about 2.7 projects that they were working on. Figure 5 illustrates the distribution of the number of projects reported by one respondent. As shown in the figure, it is skewed to the right.

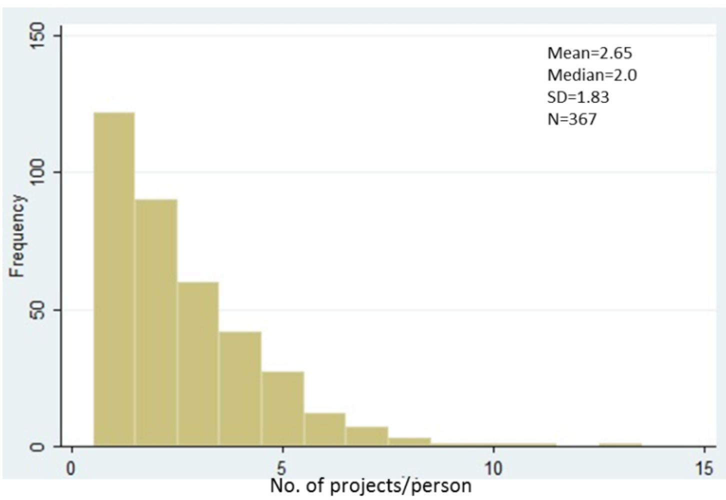


Figure 5. Number of Projects Named by Individual

The project titles named by respondents were piped into the following questions in the electronic platform of the web survey. As shown in Table V, respondents were able to answer project-specific questions based on the project names that they reported in the name-generator questions. For instance, those who named five projects in the three name-generator questions were provided with a list of five projects in the left column of the grid question and were able to check project-specific answers in a name-interpreter question. Depending on the number of projects named, different number of projects was listed in the left column of the grid questions. Duplicate projects named more than once in the three name-generator questions, because of the multiple sources of funding, were automatically screened so that respondents did not get a duplicate list of projects in the name-interpreter questions.

All in all, among the 546 respondents who completed either the 2010 survey or the 2011 survey, 367 indicated that they had active projects. Those individuals generated 973 project data that contain substantive information on projects.[16]

### 4.1.2. Survey Respondents with and without Projects

Respondents with active projects are not a random selection of the total respondents. They differ from other respondents without projects in terms of research-related aspects (Table VI). A group of respondents with projects (A) had higher percent of researchers engaged in basic, applied or development research than the other group without projects (B). T-tests show that these percentage differences were statistically significant. Even though the group with projects was intentionally selected in order to better identify the linkage between exclusive sharing and research outcomes, it is important to acknowledge the potential bias associated with this subgroup-selection and limitations in generalizing the findings to the total respondents. Therefore, the general characteristics of the group with projects (A) were compared with the ones of the other group without projects (B).

[16] The original data collected were 996 projects reported by 375 individuals, however, 23 projects reported by 8 individuals were removed because they did not contain substantive information except “none” or “no project” as a response to a question on a project title; therefore, the final number of projects was 973.

TABLE VI. COMPARISON OF RESPONDENTS WITH AND WITHOUT PROJECT-LEVEL DATA

| Individual-level Variables | Total Respondents (n=546) | Comparison of subgroups, A and B | | |
|---|---|---|---|---|
| | | Respondents with Projects (A) (n=367) | Respondents without Projects (B) (n=179) | t (df) |
| Organisms used | | | | |
| Microbes | 273/546 (50.0%) | 194/367 (52.9%) | 79/179 (44.1%) | -1.917 (544)+ |
| Livestock | 110/546 (20.1%) | 69/367 (18.8%) | 41/179 (22.9%) | 1.122 (544) |
| Aquatics | 101/546 (18.5%) | 64/367 (17.4%) | 37/179 (20.7%) | 0.912 (544) |
| Insects | 62/546 (11.4%) | 40/367 (10.9%) | 22/179 (12.3%) | 0.480 (544) |
| Place of Employment | | | | |
| Industry | 106 /546 (19.4%) | 72/367 (19.6 %) | 34/179 (19.0%) | -0.173 (544) |
| Government | 142 /546 (26.0%) | 97/367 (26.4%) | 45/179 (25.1%) | -0.322 (544) |
| University | 264 /546 (48.4%) | 186/367 (50.7%) | 78/179 (43.6%) | -1.560 (544) |
| Nonprofit and others | 30 /546 (5.5%) | 12/367 (3.3%) | 18/179 (10.1%) | 3.293 (544)** |
| Research fields (all that apply) | | | | |
| Basic Research | 304 /546 (55.7%) | 217/367 (59.1%) | 87/179 (48.6%) | -2.331 (544)* |
| Applied Research | 382 /546 (70.0%) | 280/367 (76.3%) | 102/179 (57.0%) | -4.705 (544)*** |
| Development Research | 147/546 (26.9%) | 108/367 (29.4%) | 39/179 (21.8%) | -1.892 (544)+ |
| Gender | | | | |
| Male | 367/473 (77.6%) | 277/359 (77.2%) | 90/114 (78.9%) | 0.398 (471) |
| Female | 106/473 (22.4%) | 82/359 (22.8%) | 24/114 (21.1%) | |
| Race | | | | |
| White | 398/485 (82.1%) | 308/366 (84.2%) | 90/119 (75.6%) | -2.110 (483)* |
| Other | 87/485 (17.9%) | 58/366 (15.8%) | 29/119 (24.4%) | |
| Years worked | | | | |
| Mean | 15.6 | 15.89 | 14.82 | 0.925 (476) |
| SD | 10.7 | 10.92 | 10.10 | |
| Min/Max | 1/60 | 1/60 | 1/46 | |
| N | 478 | 364 | 114 | |

***<p=0.001; **<p=0.01; *p<0.05; +p<0.10

Regarding the place of employment, the majority of respondents were affiliated with university, government, or industry. The percentages of people affiliated with university, government, or industry were not significantly different between the groups with and without projects. However, the group with projects (A) had lower percent of nonprofit researchers than the other group (B). This may suggest that nonprofit researchers were underrepresented in the group with projects (A). It would be still noteworthy that the total number of nonprofit researchers was so small (i.e., 30 out of 546 respondents) so that the percentage difference between the two groups was attributed to only a small difference in the number of nonprofit researchers (i.e., 12 versus 18 researchers).

No significant difference was found in gender composition and average number of years worked between the two groups, although a difference in racial composition was documented. The composition of organisms used appears to be roughly similar across the two groups, A and B. Microbe users accounted for about half of the sample. Each of those who used livestock or aquatic genetic materials comprised about twenty percent of the sample. Insect users were almost ten percent of the sample. No significant difference was found between the groups with and without projects (A and B) in terms of the percentages of people using livestock, aquatics, and insects. However, the percentage of people using microbes was slightly higher in the group with project (A) than one of the other group (B). Table VI summarizes descriptive statistics of the total number of respondents and two separate sub-groups that do or do not have projects on genetic materials. In addition, the results of t-tests were documented in the right column of Table VI in order to show the statistical significance of the differences between the two sub-groups.

#### 4.1.3. Post-Survey Data Collection

In addition to survey data, additional data were collected from available archival documents and organizational websites in order to supplement the missing data and cross-validate the self-reported survey data. For example, survey responses on organizational size (measured by the number of full-time employees) had 279 missing values that were reported by 109 individuals. The missing values in organizational size were further searched via organizational websites and documents archived during the sampling process. In detail, 273 project-level missing values reported by 106 individuals whose primary place of employment were either university departments or government agencies were replaced thanks to available organizational website information.

For government researchers, the website information on organizational members of the ARS subunits was primarily used. Every ARS subunit had the same website structure so that organizational member information listed under the tab, “the place and people”, of each subunit website was used to calculate the total number of organizational members. All the members except visiting scientists and student interns were considered as full-time employees. For university researchers, department website information was primarily used. For each department with which a researcher was primarily affiliated, the number of faculty members and administrative staffs were counted as full-time employees, whereas emeritus professors, visiting scholars, and post-doc affiliates were excluded from the calculation. Supplementary data collection via online searching was conducted from January 2013 to May 2013. Nonetheless, 6 cases with missing values in organization size were not replaced because of the lack of publicly available information. In total, 273 out of 279 missing cases were supplemented with values additionally searched.

In addition, secotral affiliation of survey respondents (i.e., university, government or company researchers) was cross-validated with information searched in organizational website and secondary archival data, such as CVs downloaded from the individual websites during the sampling process. Since sampling was based on organizational membership information especially for university and government researchers, the information collected during the sampling process was used as a primary source of information to cross-validate self-reported responses on sectoral affiliation in the survey. In the cross-validation process, two missing values in sectoral affiliation of respondents were supplemented with values documented in organizational websites and individual CVs.

## 4.2. Methods

First, univariate descriptive statistics and bivariate correlation analyses were conducted in order to understand basic characteristics of the data. Then, probit regression models were used to empirically test hypotheses in multivariate analyses. Probit models on exclusive sharing and research outcomes were run respectively without assuming a structural linkage between the two models. In each probit model, the marginal effect of each factor was additionally calculated in order to better understand the magnitude of the effect. The marginal effect represents how much probability of a dependent variable, Y, changes as an independent variable, X, is changed by one unit while all other variables are held at their means. The marginal effect of a binary variable, X, refers to the change in the probability of Y given the discrete change of X from 0 to 1.

Then, structural models, specifically a path model, were employed in order to investigate the sequential process through which socio-ecological factors influence scientists' exclusive sharing and subsequently influence research outcomes. The path model includes two kinds of variables: an endogenous variable (i.e., Y predicted by X) and an exogenous variable (i.e., X predicting Y). Independent variable X is exogenous because its causes are not represented in the model; X is set to be free to vary. On the other hand, dependent variable Y is endogenous because it is not free to vary but predicted by the model. Each Y has a disturbance which is essentially a residual term (i.e., unexplained variance). The disturbance of Y indicates all the possible unmeasured causes of Y as well as all the possible measurement error in Y (Kline 2005, 104-105).

Structural equation modeling (SEM) is an effective technique to simultaneously investigate the effects of both endogenous and exogenous variables (Kline 2005; Muthen 2002; Muthen and Muthen 2010). Unlike the ordinary least square (OLS) regression analysis which does not allow for endogeneity, structural equation modeling allows variables in the equation to co-vary with each other until the model is fully specified. Another advantage of structural equation modeling is its flexibility in terms of data transformation. Unlike two-stage least square modeling which restricts the endogenous variable to be ordinal-scaled and normally distributed, structural equation modeling allows endogenous variables to take on any values. SEM deals with not only ordinal values but also dichotomous or categorical values, because it incorporates an additional data transformation matrix for non-continuous values in the modeling.

Mplus 6.0 was used for the analysis given its strength in treating clustered variables as well as missing variables in structural equation modeling. Estimation was based on weighted least square (WLS) parameter estimates, because endogenous variables predicted by exogenous variables are binary variables. The WLS estimation is known to perform better than the maximum likelihood (ML) estimation when outcome variables are binary or categorical (Kline 2005, 180). Unlike the ML estimation generally assuming a true population measurement model with continuous indicators, the WLS estimation does not assume a particular distributional form of outcome variables (Kline 2005, 179). Therefore, it can reduce estimation errors associated with a normality assumption. The WLSMV estimation built in Mplus is one kind of robust weighted least square (WLS) estimations which use relatively simpler matrix calculations for computational efficiency. It uses a diagonal weight matrix with standard errors and mean- and variance-adjusted chi-square test statistics that use a full weight matrix (Muthen and Muthen 2010).[17] For binary outcome variables, it is accompanied with a probit link function in Mplus 6.0 so that the path coefficients reported in a structural model are essentially probit regression coefficients (Muthen and Muthen 2010, 638).

Since project-level data were clustered by individual respondents, both probit regression models and structural models incorporated additional complex survey design measures to adjust sampling weights and standard errors of estimation associated with cluster sampling (Asparouhov and Muthén 2006). This adjustment is expected to produce more conservative estimates compared to a traditional

[17] An alternative estimation can be the maximum likelihood (MLR) estimation which use standard errors and a chi-square test statistics that are robust to non-normality and non-independence of observations (Muthen and Muthen 2010, 533). It is used with logit link function in Mplus. It can be also used with complex survey design measures in Mplus 6.0.

modeling that simply assumes data to be collected by simple random sampling. The adjustment can reduce Type II errors that fail to reject the false statements.

## 4.3. Measures

This dissertation aims to understand the antecedents and consequences of exclusive sharing. Furthermore, it seeks to uncover a sequential process through which socio-ecological factors influence scientists' exclusive sharing and subsequently influence research outcomes. Therefore, the analyses of this dissertation are comprised of two parts. First, the antecedents and consequences of exclusive sharing are predicted independently by a probit regression model. Second, in a structural model, the first equation estimates the likelihood of exclusive sharing which is, in turn, used in the second equation to predict the likelihood of research outcomes.

### 4.3.1. Dependent Variables

The dependent variable for the first equation is exclusive sharing that occurs only among selected entities (Table VII). It was operationalized as a condition in which genetic materials were shared between an original provider and a receiver but not transferred to a third party. Restrictions on sharing with a third party, a so called *"third-party sharing restrictions (i.e. sharing restrictions),"* were measured by survey responses of whether material recipients have agreed not to transfer the genetic materials to others in each of their recent research projects (Yes = 1; No = 0). Researcher agreements on a third-party sharing restriction can be made via formal written contracts or material transfer agreements but also via informal conversations among colleagues or undocumented social contracts among multiple entities (Welch, Shin, and Long 2013). The presence of these formal and informal agreements indicates a fundamental sharing restriction imposed on each project, although the agreements do not fully capture all types of sharing restrictions. "Third-party sharing restrictions" was measured with a binary value. Those who had agreed not to transfer genetic materials to a third party were given a value of 1 indicating the presence of a third-party sharing restriction, whereas others were given a value of 0. This third-party sharing restriction was also included in the second equation that predicts the likelihood of research outcomes.

Research outcomes were operationalized as the presence of *publications* and *intellectual property outcomes (i.e. IP outcomes)* produced in each project (Table VII). Basically, a third-party sharing restriction is posited to be negatively associated with publications (Hypothesis 5) but positively associated with intellectual property outcomes (Hypothesis 6). Both publications and intellectual property outcomes were measured by survey responses. Respondents were asked to select all the research outcomes produced in each project. Then, they were given a list of four types of research outcomes: academic publications, intellectual property disclosures, patents or patent applications, and other types of intellectual property. The selection of academic publications was considered to indicate the presence of publications produced in a project (Yes =1; No=0). The selection of the other three outcomes related to intellectual property (IP) was considered to indicate that the project has produced any IP-related outcomes (any yes =1; none of them = 0).

TABLE VII. DEPENDENT VARIABLES

| Variables | Question items (values) |
|---|---|
| *Sharing restriction* | |
| Third-party sharing restrictions | For the genetic materials you obtained during the last two years on each of the projects you named, which of the following are true?<br>- I agreed not to provide the materials to others (yes=1, no=0) |
| *Research outcomes* | |
| Publications | Which of the following are the products of the project that you have worked on during the last two years? Select all that apply<br>- Academic publication (yes=1, no=0) |
| Intellectual property (IP) outcomes | - Intellectual property disclosures<br>- Patents or patent applications<br>- Other types of intellectual property<br>(any yes =1, none of them = 0) |

**4.3.2. Independent Variables**

Exclusive sharing measured by third-party sharing restriction is expected to be influenced by four sets of independent variables: 1) attributes of shared objects (i.e., market/non-market values and ecological traits of genetic materials), 2) attributes of sharing process (i.e., cross-nationality, formality, and reciprocity), 3) industry employment of sharing actors – both recipients and sources, and 4) attributes of a demand environment (i.e., commercialization).

As attributes of genetic materials, both market and non-market values of genetic materials are posited to promote exclusive sharing and generate a third party sharing restriction (Proposition 1a and 1b). As attributes of shared objects, *market value of genetic materials* was measured by a survey response of the amount of monetary payment that a researcher made for the genetic materials in each project (Table VIII). Because sensitivity surrounding costs could have resulted in non-response bias, respondents were asked a question categorized as a variable of the approximate amount of monetary payment, which resulted in three ordinal values: no charge (=1), at cost (=2), and cost plus additional fee (=3).

*Non-market value of genetic materials* embraces a broad range of societal and cultural values which cannot be reduced to monetary terms in a market exchange. The reliability of information attached to genetic materials was measured as one aspect of non-market value especially relevant to research and development because reliable information on genetic materials could represent critical values as research inputs (Campbell et al. 2002; Kaye et al. 2009). Respondents were asked to assess the reliability of available information related to the genetic materials used in each project; they were given four-point Likert scale that ranged between very reliable (=4), reliable (=3), unreliable (=2), and very unreliable (=1).

In addition, the significance of ecological conditions from which genetic materials originate can make a difference in sharing patterns given the existing interplay between social practices and ecological systems. When the ecological conditions are considered to be important, genetic materials are expected to be less exclusively shared without a third-party sharing restriction (Proposition 2). In the context of agricultural research, the *significance of ecological conditions* was operationalized as the importance of natural environment, geographic locations and events or occurrence where genetic materials were found.

A single indicator was developed based on the survey response on (1) whether the specific natural environment where the genetic materials were found is important for a research project, (2) whether the specific geographic location where the genetic materials were found is important for the project, and (3) whether the specific event or occurrence where the genetic materials were found is important for the project. If any of the three items were checked, it was considered to indicate the significance of ecological conditions (any yes =1; none of them = 0) and tested its association with a third-party sharing restriction.

TABLE VIII. MEASURES ON GENETIC MATERIALS

| Variables | Question items (values) |
|---|---|
| *Market/non-market values of GRs* | |
| Market value of GRs | How much do you pay for the GRs obtained for the projects you named? (no charge =1, at cost=2, cost plus additional fee=3) |
| Information reliability attached to GRs | How reliable is the available information for the GRs you use on the projects you named? (very unreliable=1, unreliable=2, reliable=3, very reliable=4) |
| *Significance of ecological conditions* | |
| Significance of ecological conditions | - The specific natural environment in which genetic resources were found is important for the project you named.<br>- The specific geographic locations where genetic resources were found is important for the project you named.<br>- A specific event or occurrence (e.g. disease outbreak) where genetic materials were found is important for the project you named.<br>(any yes =1, none of them = 0) |

As attributes of sharing process, this dissertation proposes cross-nationality, formality, and reciprocity as the antecedents of exclusive sharing. Cross-national sharing and formality are expected to increase exclusive sharing (Hypotheses 3 and 4), whereas reciprocal relationships between materials providers and receivers is expected to decrease the likelihood of exclusive sharing (Proposition 3).

*Cross-national sharing* was captured by a survey response on the country from which a researcher had obtained genetic materials for each project (Table IX). Any projects that used genetic materials obtained from other countries were coded 1, indicating the presence of cross-national sharing, whereas the project that had genetic materials only from the United States were coded 0.

*Formality in sharing* was operationalized as the use of material transfer agreements (MTAs) when a researcher received genetic materials from others for a research project (Table IX). Material transfer agreements are specifically designed for genetic materials transferred and are widely used as a formal procedure specifying the rights of a material provider and a receiver, not only in private but also in public sectors (Barton and Siebeck 1994; Rodriguez 2005; Streitz and Bennett 2003). Therefore, the variable for material transfer agreements would be relevant to capture the most common formal procedure associated with sharing of genetic materials. In the survey, respondents were asked to report whether MTAs were required for the genetic materials obtained for each of the projects they named. Those who said “yes” were given a value of 1 indicating the use of MTAs, whereas others were given a value of 0.

*Reciprocity in sharing* refers to a sharing process in which a material recipient is obliged to compensate the sender for the given materials by giving something back (Haeussler 2011, 108). The reciprocation is essentially based on the expectation or agreement between a material provider and a receiver. The presence of expected returns between the two parties has been used as an indicator of reciprocity in several studies (Blau 1964; Shibayama and Baba 2011; Shibayama, Walsh, and Baba 2012). In a study of material-sharing in life and material sciences, Shibayama and colleagues (2012) measured reciprocity between a material provider and a receiver using a survey response addressing whether a material recipient was expected to provide any types of rewards, such as co-authorship, acknowledgement, data and materials in return. In agricultural research, reciprocal returns in exchange for genetic materials can include information on research findings, training or education services, technical services, authorship or intellectual-property rights, and other monetary and non-monetary resources (Brahy and Louafi 2007; Visser et al. 2005). Hence, this study measured reciprocity in sharing using a survey response about whether a researcher was expected to provide any type of educational, technical, and research-related services in return for material providers (Table IX). Those who were expected to provide any type of service (i.e., storage of the genetic materials, research or technical services, information sharing on project results, or education and training) were given a value of 1 indicating the presence of expected returns, whereas those who did not select any were given a value of 0.

TABLE IX. MEASURES ON SHARING PROCESS

| Variables | Question items (values) |
|---|---|
| *Cross-national sharing* | |
| GRs obtained from abroad | From which of the following areas is the GRs obtained for the projects you named? Select all that apply.<br>- United States / Canada, Australia or New Zealand / European Countries / Japan or Korea / China/ Africa/ Central or South America / Russia or Central Asian States/ South or Southeast Asia/ Don't know<br>(any yes except U.S. =1, United States or none of them = 0) |
| *Formality in sharing*<br>Use of MTAs | Which of the following are required for the GRs obtained from either US sources or foreign sources for the projects you named?<br>- Material transfer agreement (yes =1, no=0) |
| *Reciprocity in sharing* | |
| Expected non-monetary returns | For the GRs you obtained on each of the projects you named, which of the following are you expected to provide in return? Select all that apply.<br>- Storage of the material<br>- Research or technical services<br>- Information on project results<br>- Education and training<br>(any yes =1, none of them=0) |

As attributes of sharing actors, industry affiliation of individuals – both material recipients and providers – are examined. Both industry providers and receivers of genetic materials are hypothesized to be more likely to engage in exclusive sharing while imposing a third-party sharing restriction (Hypotheses 1 and 2).

*Industry employment of material recipients* was identified by a survey response on the primary place of employment and cross-validated by secondary archival data and website information on organizational members (Table X). If a researcher who had obtained genetic materials from others was primarily affiliated with private industry including trade associations, he or she was categorized as an industry researcher. Others who were affiliated with government, university and non-profit organizations (neither university nor government) were categorized as non-industry researchers. *Industry employment of material providers* was primarily identified by survey responses on the source of genetic materials (Table X). If genetic materials were obtained from industry sources, a value of 1 was given. For industry researchers, repositories in their own companies, as well as other companies, were considered as industry sources. If the materials were obtained from other sources, such as government or university sources, a value of 0 was given.

TABLE X. MEASURES ON SHARING ACTORS

| Variables | Question items (values) |
|---|---|
| Industry recipients | Which of the following sectors is your primary place of employment?<br>- University or college (=0)<br>- Government organization or agency (=0)<br>- Private industry including trade associations (=1)<br>- Non-profit (not government or university) (=0) |
| Industry sources | For each of the projects you named, where do you the GRs come from?<br>- Government sources (=0)<br>- University sources (=0)<br>- Industry sources (own company and other companies) (=1) |

Lastly, as attributes of demand environment, the theoretical model proposes that both scientific competition and commercialization will influence exclusive sharing. However, the empirical model in this dissertation only examines the effects of commercialization, because measures of scientific competition are not available in the dataset. Commercialization in a research environment is hypothesized to be positively associated with a third party sharing restriction (Proposition 4) because it incentivizes and legitimizes exclusive sharing in science.

*Commercialization* was measured by three observed variables: development research, industry funding, and industry collaborators. These three items are frequently used as indicators of commercialization in a research environment (Blumenthal et al. 2006; Evans 2010; Haas and Park 2010; Walsh, Cohen, and Cho 2007). Hong and Walsh (2009) used a variable of industry collaborator as one of the indicator of commercialization. Campbell and colleagues (2000) asked whether a respondent had received funds from industry and used the response as one of the indicator of commercialization. Nonetheless, the three variables are not necessarily converged into one latent variable given the divergent practices in industry interactions. Not only development research but also basic and applied research is often conducted with intensive interactions with industry collaborators (Agrawal 2001; Goldberger et al. 2005). Having industry collaborators does not necessarily mean the presence of industry funding. Hence, the three items were measured individually and tested their associations with a third-party sharing restriction (Table XI).

*Development research* was measured by a survey response on the characteristics of a research project. Projects designed for product or process development were counted as development research (=1), whereas all the other types of research were coded as non-development research (=0). *Industry funding* was measured by administrative coding on whether a reported research project was fully or partially funded by the private sector. The variable of *industry collaborators* was measured as the survey response on sectoral affiliation of research collaborators in a project. Those who reported that one or more of their collaborators were affiliated primarily with private industry were coded 1 indicating the presence of industry collaborators on the project.

TABLE XI. MEASURES ON RESEARCH ENVIRONMENT

| Variables | Question items (values) |
|---|---|
| *Commercialization* | |
| Development research | How would you characterize the work on the projects you named? Select all that apply.<br>- Basic research (=0)<br>- Applied research (=0)<br>- Technical (=0)<br>- Product development (=1)<br>- Process development (=1) |
| Industry funding | [Name generator question] Please name the projects using GRs that were fully or partially funded by the private sector.<br>(Named =1, not named =0)<br><br>For industry researchers, the funding from the private sector include funding from other companies as well as their own company |
| Industry collaborators | For the projects you named, please indicate whether any of your collaborators are primarily affiliated with:<br>- University or college (=0)<br>- Government organization or agency (=0)<br>- Private industry (=1)<br>- Nonprofit (not government or university) (=0)<br>For industry researchers, private industry include their own company as well as other companies |

### 4.3.3. Control Variables

The probit and structural equation models of this dissertation comprise two parts: the models predicting the likelihood of exclusive sharing and the models predicting research outcomes. The first model predicting the likelihood of exclusive sharing controlled for individual and organizational capacities of material recipients for two reasons. First, individual and organizational capacities (such as financial and technical resources) lay out the basic condition in which individual scientists exert their discretion of whether to share or not. Limited technical and financial resources can restrict scientists from providing genetic materials to a third party although they are willing to do so (Reinholt, Pedersen, and Foss 2011; Walsh, Cohen, and Cho 2007). On the other hand, slack resources and professional work experiences enable individuals to hold professional authority and negotiation power (Campbell et al. 2000;

Molm, Peterson, and Takahashi 1999), which can reduce constraints and barriers on a third-party transfer imposed by another party. In fact, Haeussler and colleagues (2009) found that individuals who obtained tenures and large organizations are more likely to share their genetic materials with others. Hence, it would be necessary to control for individual and organizational capacities in order to separate out variation caused by resource constraints or negotiation power across individuals/organizations.

A control for individual capacity as a professional researcher was indirectly measured by a respondent's (a material recipient) years of employment. The number of years worked in a current organization ranged from 1 to 60, with a mean value of 16 years. Organizational capacity was partially captured by the size of an organization. Organization size was measured by a numeric response on the number of full-time employees of an organization where a material recipient worked. Organization ranged from 1 to 13,000. Given the highly skewed distribution, data on organization size were transformed via natural logarithms (Figure6). The logged values ranged from 0 to 12 and the average value was 4.01.

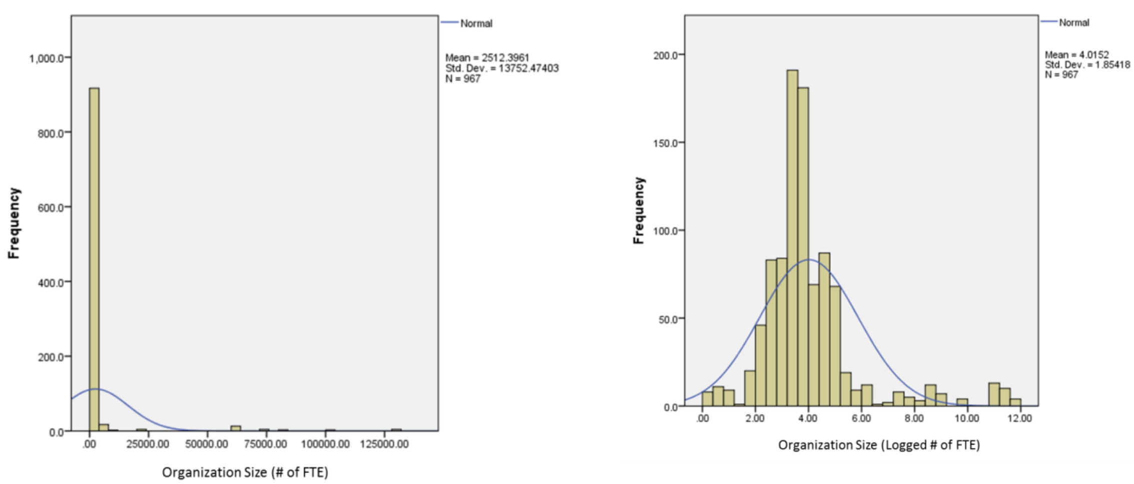


Figure 6. Logarithmic Transformation of Organization Size

The second model predicting the likelihood of producing research outcomes controlled for individual and collective team attributes of all research project members in order to examine independent effects of exclusive sharing on research outcomes. Given the relatively different missions and incentive structures institutionalized in each sector (Aghion, Dewatripont, and Stein 2008; Sauermann and Stephan 2013), the model included a control for sectoral affiliation of project members. Sectoral affiliation of project members was measured by survey responses on respondents' primary place of employment as well as sectoral affiliations of their collaborators in each of the projects named. In terms of research collaborators, about 60% of projects reported the presence of university collaborators and 36% of projects used government collaborators.

Both equations of exclusive sharing and research outcome controlled for four different families of organism – livestock, insects, aquatics, and microbes. This is because these four groups of organisms vary not only in terms of the biological conditions in which the genetic materials are produced and reproduced but also in terms of the technical, economic and legal conditions in which genetic materials are searched, deposited, and distributed (Anderson and Centonze 2007; Dedeurwaerdere 2010; Long and Blackburn 2011). Different organisms are subjected to different legal and regulatory frameworks. Microbial genetic materials are covered by the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, so that intellectual property rights related to microbes are commonly acknowledged across nations (Roffe 2008). The established intellectual property rights protection for microbial genetic materials contrasts with the localized legal frameworks for insects and aquatic animals. The exchange of honey bees in the US is highly regulated by the Animal and Plant Health Inspection Services (APHIS), whereas the exchange of cattle genetic materials mostly occurs in a self-regulated market system. A cattle market for genetic materials is well developed, whereas the market for aquatic genetic materials is now emerging (Long and Blackburn 2011). Culture collections or conservation facilities also vary, ranging from small private repositories of aquatics to large-scaled public microbial culture collections. These different regulatory and distributional arrangements for different organisms can precondition sharing of genetic materials among individual scientists. Sub-fields of particular organisms can develop a meso-level field norms for material-sharing and can influence individual decisions on whether to share (Haas and Park 2010). Therefore, three dummy variables (*livestock, aquatics, and insects*) were included in the model predicting the likelihood of sharing restriction, whereas *microbes* was used as a reference group.

As shown in Table XII, the project-level data comprise research projects using microbes, livestock, aquatics and insects. Almost half of project data were about microbes, whereas projects on livestock, aquatics, and insects accounted for 22%, 18% and 12% of the total projects, respectively.

These three dummy variables were also included in the model predicting research outcomes as control variables because scientific disciplines related to different organisms can vary in terms of the level of scientific competition and research priority granted in the field. Publications can be more valued in some fields, while patents and other intellectual property outcomes are more important in other fields. Hence, scientists' willingness to produce a certain type of research outcome can differ according to the institutionalized reward structures and granted norms in each research field. Moreover, the probability of producing a certain research outcome can vary depending on the size, maturity and competitiveness of a research field. Therefore, four different research fields associated with four different organisms were controlled for in the model on research outcome. Table XII presents brief descriptive statistics of all the variables used in the model.

TABLE XII. DESCRIPTIVE STATISTICS

| Variables | N | Min/Max | Mean | SD |
|---|---|---|---|---|
| **Dependent Variables** | | | | |
| Third-party transfer restrictions | 973 | 0/1 | 0.216 | 0.412 |
| Publications | 971 | 0/1 | 0.762 | 0.426 |
| Intellectual property outcomes | 971 | 0/1 | 0.219 | 0.414 |
| **Independent Variables** | | | | |
| Market value of GRs | 917 | 1/3 | 1.401 | 0.632 |
| Information reliability attached to GRs | 931 | 1/4 | 3.156 | 0.873 |
| Significance of ecological traits | 973 | 0/1 | 0.583 | 0.493 |
| GRs obtained from abroad | 973 | 0/1 | 0.247 | 0.431 |
| Use of MTAs | 973 | 0/1 | 0.276 | 0.447 |
| Expected non-monetary returns | 973 | 0/1 | 0.706 | 0.455 |
| Industry sources | 973 | 0/1 | 0.447 | 0.497 |
| Industry /recipients | 973 | 0/1 | 0.226 | 0.418 |
| Commercialization | | | | |
| Development research | 973 | 0/1 | 0.268 | 0.443 |
| Industry funding | 973 | 0/1 | 0.290 | 0.450 |
| Industry collaborators | 973 | 0/1 | 0.411 | 0.492 |
| **Controls** | | | | |
| Years worked | 963 | 1/60 | 15.78 | 10.83 |
| Organization size | 967 | 1/13,000 | 2,512 | 13,752 |
| Logged value of Organization size | 967 | 0/11.78 | 4.010 | 1.850 |
| University collaborators | 973 | 0/1 | 0.596 | 0.490 |
| Government collaborators | 973 | 0/1 | 0.364 | 0.481 |
| Microbes | 973 | 0/1 | 0.487 | 0.500 |
| Livestock | 973 | 0/1 | 0.219 | 0.414 |
| Aquatics | 973 | 0/1 | 0.175 | 0.380 |
| Insects | 973 | 0/1 | 0.117 | 0.321 |

## 4.4. Missing Data and Methods used for Missing Data

### 4.4.1. Missing Data

Survey data used in this dissertation contain item non-responses. As shown in Table XIII, a majority of item non-responses were attributed to the missing values in two variables: market value and information reliability. List-wise deletion of the observations with item non-responses resulted in a sample of 884 projects drawn from 340 individuals.

TABLE XIII. PERCENTAGE OF ITEM-NONRESPONSE

| Variable names | Number of project-level observations (number of individuals without missing items) | Number of project-level missing items (number of individuals with missing items) | Percentage of project-level missing items (percentage of individuals with missing items) |
|---|---|---|---|
| Sharing restrictions | 973 (367) | 0 (0) | 0.0% (0.0%) |
| Publications | 971 (366) | 2 (1) | 0.2% (0.3%) |
| IP outcomes | 971 (366) | 2 (1) | 0.2% (0.3%) |
| Market value of GRs | 917 (341) | 56 (26) | 5.7% (7.1%) |
| Information reliability | 931 (349) | 42 (18) | 4.3% (4.9%) |
| Years worked | 963 (364) | 10 (3) | 1.0% (0.8%) |
| Organization size | 967 (364) | 6 (3) | 0.6% (0.8%) |
| Total Net | 884 (340) | 89 (27) | 9.1% (7.3%) |

Given the potential item-nonresponse bias, a dummy variable indicating the presence of any missing items was created and used to check whether the missing items are completely at random (MCAR) or not (Table XIV). The mean comparison of the groups with and without missing items suggests that the item-nonresponse is not MCAR. Item-nonresponse appears to be associated with the place of employment; projects reported by university researchers had fewer missing items, whereas projects reported by company researchers had more missing items.

TABLE XIV. COMPARISON OF PROJECTS WITH AND WITHOUT MISSING ITEMS

| | Comparison of Mean Values between A and B | | | Total Projects (n=973) | Imputed average values (no. of imputed cases) |
|---|---|---|---|---|---|
| | Cases w/o missings (A) (n=884) | Cases w/ missings (B) (n=89) | t (df) | | |
| **Dependent Variables** | | | | | |
| Third-party sharing restriction | 0.224 | 0.146 | -1.701 (971) + | 0.217 | |
| Publications | 0.774 | 0.644 | -2.726 (969) ** | 0.761 | |
| IP outcomes | 0.221 | 0.207 | -0.294 (969) | 0.219 | |
| **Independent Variables** | | | | | |
| Market value | 1.408 | 1.212 | -1.752 (915)+ | 1.401 | 1.395 (56) |
| Information reliability | 3.151 | 3.255 | 0.793 (929) | 3.156 | 3.151 (42) |
| Significant ecological conditions | 0.590 | 0.516 | -1.343 (971) | 0.583 | |
| GRs obtained from abroad | 0.254 | 0.179 | -1.557 (971) | 0.248 | |
| Use of MTAs | 0.297 | 0.067 | -4.673(971)*** | 0.276 | |
| Expected returns | 0.741 | 0.359 | -7.750 (971)*** | 0.706 | |
| Industry sources | 0.448 | 0.438 | -0.176 (971) | 0.447 | |
| Industry recipients | 0.214 | 0.337 | 2.632 (971)** | 0.226 | |
| Development research | 0.250 | 0.449 | 4.078 (971)*** | 0.268 | |
| Industry funding | 0.214 | 0.337 | 1.719 (971)+ | 0.290 | |
| Industry collaborators | 0.394 | 0.573 | 0.548 (971)** | 0.411 | |
| **Controls** | | | | | |
| Years worked | 10.53 | 13.68 | 1.684 (961)+ | 15.78 | 15.84 (10) |
| Organization size | 2,634 | 1,213 | -0.900 (965) | 2,512 | |
| Logged value | | | | 4.010 | 4.004 (6) |
| University collaborators | 0.604 | 0.516 | -1.599 (971) | 0.596 | |
| Government collaborators | 0.372 | 0.292 | -1.495 (971) | 0.364 | |
| Microbes | 0.486 | 0.494 | 0.143 (971) | 0.487 | |
| Livestock | 0.224 | 0.179 | -0.959 (971) | 0.219 | |
| Aquatics | 0.173 | 0.202 | 0.689 (971) | 0.175 | |
| Insects | 0.116 | 0.123 | 0.198 (971) | 0.117 | |
| **Auxiliary data** | | | | | |
| Gender (=Male) | 0.759 | 0.717 | -0.850 (955) | 0.760 | |
| Race (=White) | 0.084 | 0.083 | -0.369 (969) | 0.841 | |
| University recipients | 0.494 | 0.348 | -2.635 (971)** | 0.481 | |
| Government recipients | 0.256 | 0.269 | 0.264 (971) | 0.258 | |
| Nonprofit recipients | 0.033 | 0.044 | 0.539 (971) | 0.035 | |
| Basic research | 0.480 * | 0.348 | -2.391 (971)* | 0.469 | |
| Applied research | 0.590 | 0.606 | 0.297 (971) | 0.592 | |

***<p=0.001; **<p=0.01; *p<0.05; +p<0.10

Not only industry employment but also various interactions with industry seem to influence the tendency not to report specific questions. Whether to have industry collaborators or conduct development research was significantly associated with the presence of missing items. Moreover, having material transfer agreements or expected non-monetary returns was also positively associated with the existence of item-nonresponses. The identified patterns suggest that item-nonresponse is not completely at random. However, the findings also suggest that item-nonresponse can be predicted by other socio-demographic factors instead of being predicted by the item itself. Within each class that is predicted by other socio-demographic factors, item-nonresponse can be at random. In this regard, existing item-nonresponse in the data can be said to be missing at random (MCR), even though it is not missing completely at random (MCAR).

#### **4.2.2. Methods Used for Missing Data**

Missing at random in survey data is commonly found in survey research (Brick and Kalton 1996; Little and Rubin 2002); missing at random (MCR) is more common than missing completely at random (MCAR) in social science. Nonetheless, potential bias caused by item nonresponses cannot be ignored. Therefore, multivariate analyses were first run with a list-wise deletion of missing items. In addition, the same analyses were done with the imputed data in order to cross-validate the findings from the original data. The comparison of the results run with and without imputed dataset is expected to help understand the potential estimate bias associated with item nonresponses.

Multiple imputations based by chained equations (MICE) were conducted to create the imputed data. MICE is one of the most commonly used techniques in recent works dealing with missing data (Graham, Olchowski, and Gilreath 2007). In fact, MICE is expected to generate more reliable estimates than traditional methods of dealing with missing data (Baraldi and Enders 2010; Graham, Olchowski, and Gilreath 2007). First, it can produce more reliable estimates than a traditional list-wise deletion. That is not only because the MICE use all the cases and has more power in significance tests compared to the list-wise deletion but also because it can reduce bias of the estimates caused by blind deletion of missing cases. Baraldi and Enders (2010) point out that a list-wise deletion is only allowable when the missingness is completely at random (MCAR) so that the deletion of missing data does not lead to any change in the variables of interest. Second, MICE better performs than other single imputation methods, including hot deck imputation and regression imputation (Baraldi and Enders 2010; Little and Rubin 2002). Assigning one single value to a missing case is too deterministic to rule out other variability that is present (Baraldi and Enders 2010). Acknowledging the disadvantages of a single imputation methods, recent works (Little and Rubin 2002; Peytchev 2012) have increasingly promoted the use of multiple imputation methods based on maximum likelihood estimation. Multiple imputation methods are considered to be effective in dealing not only with missing completely at random (MCAR) but also with missing at random (MCR) (Baraldi and Enders 2010). Multiple imputations by chained equation (MICE) is one of the efficient multiple imputation techniques based on maximum likelihood estimation. This dissertation employed MICE that is available in statistical software, Stata.

In multiple imputation processes, all the variables included in the analytical model were used to predict the multiple sets of values substituting missing values. Missing values in not only independent variables but also in dependent variables were imputed and used for the estimation of the other missing values as recommended by the previous research (von Hippel 2007). Based on a general recommendation on multiple imputation (White, Royston, and Wood 2011), informative auxiliary variables, such as the demographic characteristics of respondents (gender and race), and the research characteristics of projects (i.e., basic research or applied research), were also used in the imputation process, even though they were not included in the analytical model. Nonetheless, the imputed values of dependent variables (i.e. outcome variables) were not used in the final analyses because imputed outcome values can engender additional needless errors in estimates (von Hippel 2007). Multiple imputation generates five sets of imputed data, which is sufficient enough to capture variability in the predicted missing values (Graham, Olchowski, and Gilreath 2007). Table XIV presents an average value of imputed values for each variable that was imputed by the MICE.

Given the nested structure of data, additional adjustments were made based on the available guidelines (Sarkisian 2010 ; White, Royston, and Wood 2011). First, the multiple imputations were performed at the individual level. Project-level data were averaged for each individual and integrated with individual-level data before the individual-level missing items were imputed. In this way, multiple imputations of the individual-level missing data (i.e., the number of years worked and organizational size) were able to utilize a full array of information available at the individual and project-levels. Second, the missing values in the project-level variables were imputed with using the original and imputed values of individual-level variables and data from the original project-level variables. Throughout the imputation process, an individual identification number was used as a cluster indicator in order to adjust variations in the nested data (i.e., project-level data clustered at the individual level). These adjustments were inevitable to avoid clustering bias in the MICE which is not designed for the multi-level data (Sarkisian 2010 ). Nonetheless, it is noteworthy that clustering effects were treated as fixed effects in the MICE, which can be better adjusted with alternative techniques modeling cluster effects as random effects (Lloyd et al. 2013).

## 4.5. Summary

What socio-ecological factors influence scientists' exclusive sharing of genetic materials? And what are the consequences of exclusive sharing in terms of research outcomes? These two primary questions were aimed to be answered with an empirical model in this dissertation (Figure 7).  Exclusive sharing was measured by survey responses on whether scientists had agreed not to share genetic materials with a third party. Exclusive sharing was predicted by four sets of antecedents, attributes of shared objects, sharing actors, sharing process and demand environment.

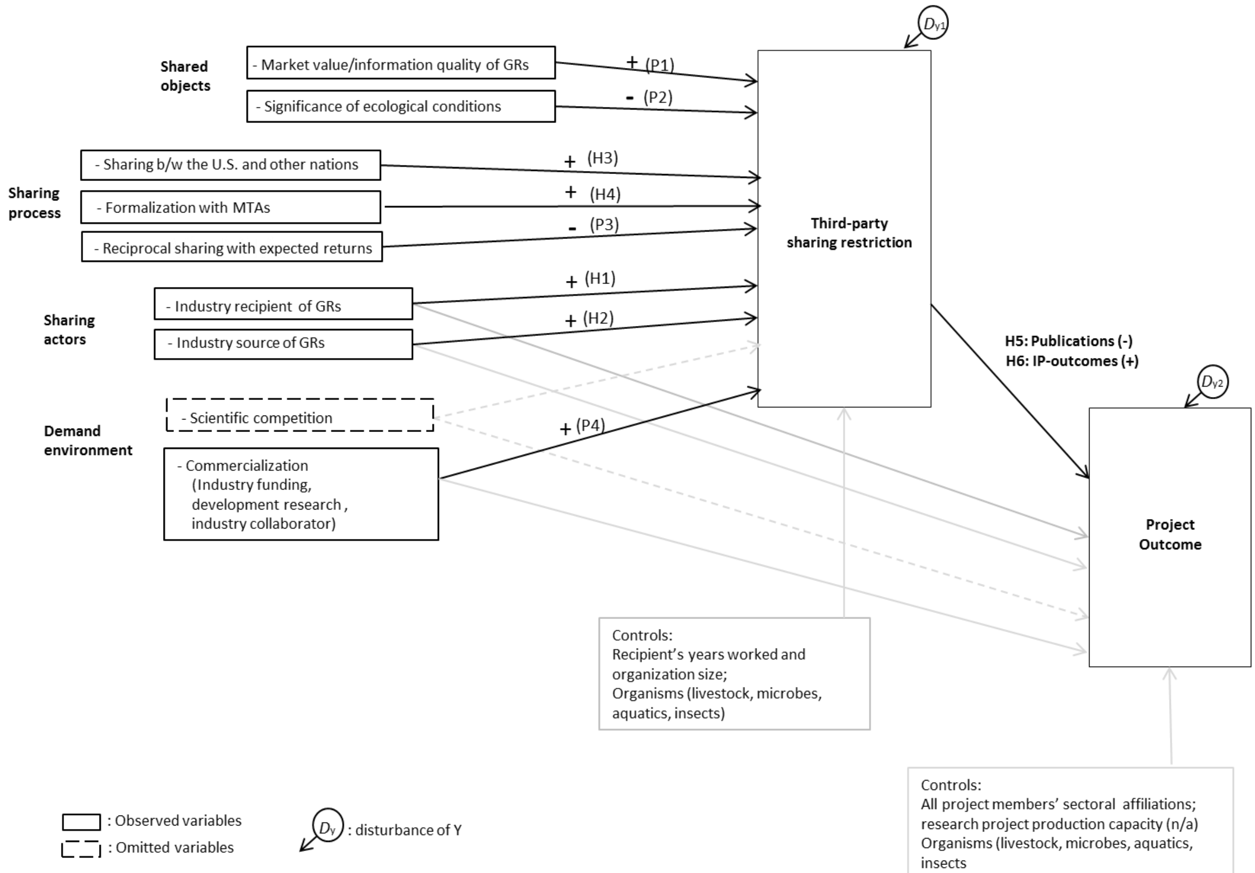


Figure 7. Empirical Model

As attributes of shared objects, greater market value of genetic materials is hypothesized to be positively associated with the likelihood of having a third-party sharing restriction (Proposition 1a). Higher non-market value measured by the reliability of information attached to genetic materials is also hypothesized to be positively associated with a sharing restriction (Proposition 1b). On the other hand, the significance of ecological traits is posited to be negatively associated with a third-party sharing restriction (Proposition 2).

As attributes of sharing process, cross-national sharing required for genetic materials from abroad is expected to entail third-party sharing restrictions (Hypothesis 3). Formalization accompanied with material transfer agreements is also hypothesized to engender third-party sharing restrictions (Hypothesis 4). However, reciprocity – measured by the presence of non-monetary returns expected by material providers – is posited to decrease the likelihood of having sharing restrictions (Proposition 3).

Moreover, industry researchers are hypothesized to be more likely to set a third-party sharing restriction, compared to university and government researchers (Hypothesis 1). When genetic materials are from industry sources, they are also expected to be more likely shared exclusively without a third-party transfer (Hypothesis 2). As an attribute of the demand environment, only commercialization was included in the empirical model because of the lack of data on scientific competition. Commercialization of research environment, measured by three observed variables on development research, industry funding, and industry collaborator, is hypothesized to provoke third-party sharing restrictions (Proposition 4).

The predicted third-party sharing restriction is again incorporated into the second equation of research outcome. The restriction is posited to be negatively associated with publications (Hypothesis 5) but positively associated with intellectual property outcomes (Hypothesis 6). Figure 7 visualizes all the relationships hypothesized in the empirical structural model.

# 5. FINDINGS

This dissertation used structural models and probit regression models in order to investigate the antecedents and consequences of exclusive sharing. In particular, structural models were used to assess the sequential process through which socio-ecological factors influence scientists' exclusive sharing and subsequently influence research outcomes. This chapter first summarizes descriptive statistics and bivariate correlations among variables included in the multivariate analyses. Then, it reports results of probit models and structural models with and without multiple imputations. Implications of each finding are further discussed.

## 5.1. Univariate Statistics

Descriptive statistics provide a basic understanding of the study sample and variables of interest. Table XV illustrates univariate statistics of dependent variables included in the empirical models.

Exclusive sharing appears to occur at times in agricultural research. In more than twenty percent of agricultural research projects (i.e., 21.7%), researchers agreed not to transfer genetic materials to a third party. This is not directly comparable with the figures reported in previous studies because of the difference in measurement. However, the percentage of projects accompanied with a third-party sharing restriction appears to be almost equivalent to the denial rate of 20 % (i.e., the percentage of requests for genetic materials denied out of the total requests) reported in biomedical research (Walsh et al. 2007), and a bit higher than the denial rates (6 to 12 %) reported in agricultural research (Shibayama and Baba 2011; Shibayama, Walsh, and Baba 2012).

Regarding research outcomes, over three quarters of all research projects were reported to produce journal publications in the last two years (Table XV). During the same period, less than a quarter of research projects produced any type of intellectual property (IP) outcomes: IP disclosures, patent applications, patents and other types of IP outcomes. Eight percent of the projects had disclosed intellectual property during the last two years, and 9.5% of the projects had patents or patent applications during the same period. A similar amount of projects were also found to produce other types of intellectual property. Overall, the total number of projects that had any type of these IP outcomes was 213, which accounted for 22% of the study sample.

TABLE XV. DESCRIPTIVE STATISTICS: DEPENDENT VARIABLES

| Variables | Min/Max Values | N | Total N | Mean Value | SD |
|---|---|---|---|---|---|
| Third-party sharing restrictions | Yes (=1) | 211 | 973 | 0.217 | 0.412 |
| | No (=0) | 762 | | | |
| Publications | Yes (=1) | 740 | 971 | 0.762 | 0.426 |
| | No (=0) | 231 | | | |
| IP outcomes | Any Yes in the following (=1) | 213 | 971 | 0.219 | 0.414 |
| | -Intellectual property disclosures | 80 | | | |
| | -Patents or patent application | 93 | | | |
| | -Other types of intellectual property | 97 | | | |
| | No (=0) | 758 | | | |

As the attributes of genetic materials, market value was measured as the basis of payment made for genetic materials. As shown in Table XVI, a majority of the materials used in agricultural research were available without any monetary payment; 68% of the projects indicated that genetic materials used in the projects were obtained without any charge. About 24% of the projects reported to purchase the materials at cost, and only 8% of the projects were found to pay costs and additional fees for genetic materials. The low percentage of monetary payments suggests that genetic materials used in agricultural research are not fully incorporated into a market system. This may be attributed to scientists' common practices to obtain genetic materials from peer-to-peer networks instead of the market as reported in previous studies (Stern 2004; Welch, Shin, and Long 2013).

Nonetheless, the lack or underutilization of a market price system does not necessarily equate the lack of potential market and non-market values of genetic materials (Padmanabhan and Jungcurt 2012; Polski 2005). Despite the infrequency of monetary payments for genetic materials, the information value of genetic materials appears to be widely recognized among agricultural scientists. Over 86 % of research projects indicated that information attached to genetic materials was very reliable or reliable, whereas only 14 % of the projects reported poor information quality.

The significance of ecological conditions is also largely acknowledged in agricultural research. In more than half of the projects, ecological conditions from which genetic materials originated were considered important for the projects. More specifically, the proportions of projects reporting the significance of geographic location, natural environment, and natural events were 35.5%, 35.8% and 34.3% respectively.

TABLE XVI. DESCRIPTIVE STATISTICS: VARIABLES ON GENETIC MATERIALS

| Variables | Min/Max Values | N | Total N | Mean Value | SD |
|---|---|---|---|---|---|
| Market value of GRs | No charge (=1) | 622 | 917 | 1.401 | 0.632 |
| - | Paid at cost (=2) | 222 | | | |
| - | Paid more than cost (=3) | 73 | | | |
| Information reliability attached to GRs | Very unreliable (=1) | 85 | 931 | 3.156 | 0.873 |
| | Unreliable (=2) | 38 | | | |
| | Reliable (=3) | 454 | | | |
| | Very reliable (=4) | 354 | | | |
| Significance of ecological conditions | Any Yes in the following (=1) | 568 | 973 | 0.583 | 0.493 |
| | -Geographic location | 346 | | | |
| | -Natural environment | 349 | | | |
| | -Event or occurrence | 334 | | | |
| | No (=0) | 405 | | | |

Three aspects of the sharing process were empirically measured in this dissertation: cross-national sharing, formalization, and reciprocity (Table XVII). First, cross-national sharing of genetic materials was measured using the survey response on whether genetic materials used in a project were from foreign countries. Approximately, a quarter of projects were found to have genetic materials from foreign countries. Major foreign sources were European countries, Canada, New Zealand and Australia, but roughly 10% of US agricultural research (96 out of 973 projects) also reported the use of genetic materials obtained from any other areas in Asia, America and Africa.

TABLE XVII. DESCRIPTIVE STATISTICS: VARIABLES ON SHARING PROCESS

| Variables | Min/Max Values | N | Total N | Mean Value | SD |
|---|---|---|---|---|---|
| GRs obtained from abroad | Any Yes in the following (=1) | 241 | 973 | 0.247 | 0.431 |
| | -European countries | 111 | | | |
| | -Canada, Australia, or New Zealand | 85 | | | |
| | -Central or South America | 36 | | | |
| | -South or Southeast Asia | 27 | | | |
| | -Japan or Korea | 16 | | | |
| | -China | 13 | | | |
| | -Russia or Central Asian States | 14 | | | |
| | -Africa | 14 | | | |
| | -Don’t know | 48 | | | |
| | No (=0) | 732 | | | |
| Use of MTAs | Yes (=1) | 269 | 973 | 0.276 | 0.447 |
| | No (=0) | 704 | | | |
| Expected non-monetary returns | Any Yes in the following (=1) | 687 | 973 | 0.706 | 0.455 |
| | - information on project results | 587 | | | |
| | - research or technical services | 263 | | | |
| | -education or training | 161 | | | |
| | -storage of genetic materials | 156 | | | |
| | No (=0) | 286 | | | |

Second, formalization of the sharing process was measured by the use of material transfer agreements (MTAs). About 28 % of research projects were found to have MTAs when obtaining genetic materials from others. They comprise 32% of the projects reported by industry researchers and 26% of the projects by university and government researchers. As reported in earlier studies (Barton and Siebeck 1994; Walsh, Cohen, and Cho 2007), MTAs were more commonly used in industries than universities or the government. The percentage of MTA use at the project-level was seemingly low compared to the figures reported by other works (Lei, Juneja, and Wright 2009). Nonetheless, one needs to be aware of the difference in measurement. In this study, the use of MTAs was analyzed at the project-level, whereas previous studies measured it at the individual level. Since one individual can be involved in multiple projects, the probability of using MTAs will increase if the unit of analysis moves from a project to an individual. In fact, a recent analysis using one of the survey data used in this dissertation (Welch, Shin, and Long 2013) shows that the percentage of individuals who use MTAs is higher than that found at the project level. On average, about 30% of respondents from university and government sectors were reported to use MTAs when exchanging genetic materials with others (Welch, Shin, and Long 2013). This is quite similar to previous findings (Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007) on researchers' use of MTAs.

Third, reciprocity between material providers and receivers was measured by whether material receivers were expected to return any types of non-monetary benefit to material providers. Overall, expected non-monetary returns from material providers were commonly present in the material-sharing process. About 71 % of projects indicated that genetic materials were obtained under a certain expectation of non-monetary services from material providers. This is consistent with previous findings (Shibayama and Baba 2011). Shibayama and Baba (2011) shows that a majority of researchers (about 77% of the study sample) expected non-monetary as well as monetary returns (e.g., coauthorship, acknowledgement in publications, data feedbacks and research fund) when they provided genetic materials to others. As non-monetary returns, material receivers said that material providers wanted to be informed about project results the most. Material providers' expectation of research or technical services, education or training, and storage services in return were also acknowledged by materials receivers.

Industry employment was studied as the attributes of sharing actors (Table XVIII). The proportion of material receivers affiliated with industry was contingent on the survey sample composition of this study. As introduced earlier in Chapter 4, the study sample included 85 individuals working in private companies; they reported about their experiences of material-acquisition and subsequently produced research outcomes in 258 projects. Therefore, research projects that have industry receivers account for 23% of the total projects.

TABLE XVIII. DESCRIPTIVE STATISTICS: INDUSTRY ACTORS AND COMMERCIALIZATION

| Variables | Min/Max Values | N | Total N | Mean Value | SD |
|---|---|---|---|---|---|
| Industry sources | Yes (=1) | 435 | 973 | 0.447 | 0.497 |
| | No (=0) | 583 | | | |
| Industry recipients/respondents | Yes (=1) | 220 | 973 | 0.226 | 0.418 |
| | No (=0) | 753 | | | |
| Commercialization in research environment | | | | | |
| Development research | Yes (=1) | 261 | 973 | 0.268 | 0.443 |
| | No (=0) | 712 | | | |
| Industry funding | Yes (=1) | 284 | 973 | 0.292 | 0.450 |
| | No (=0) | 689 | | | |
| Industry collaborators | Yes (=1) | 400 | 973 | 0.411 | 0.492 |
| | No (=0) | 573 | | | |

The survey asked whether genetic materials used in each project were from an industry setting. Almost 45% of research projects reported industry as a source. This suggests that agricultural research utilizes a great deal of genetic materials from industry instead of relying solely on public gene banks or open sources. Several empirical studies report a recent tendency in which university agricultural scientists seek more resources from industry (Glenna et al. 2007; Goldberger et al. 2005). In particular, Welch et al. (2013) shows that genetic materials used in agricultural research are overwhelmingly exchanged across university, government, and industry settings (141). Therefore, it is not surprising to see a relatively large proportion of genetic materials coming from industry sources.

The same insight can be applied to interpret the high proportion of projects which use industry collaboration and funding. As predicted throughout the literature (Glenna et al. 2007; Goldberger et al. 2005; Lei, Juneja, and Wright 2009), collaboration with industry is commonplace in agricultural research. In this study, more than 40% of research projects were found to have industry collaborators, and about 30% of projects were found to be supported fully or partially by industry funding. Development research accounted for 27% of the projects.

## 5.2. Bivariate Statistics

Bivariate correlation analysis is used to assess the direction (+/-) and strength of the bivariate relations among variables. The analysis also provides a basic understanding of the association between a predicted variable and a predicting variable. Therefore, a summary of propositions and hypotheses developed in this dissertation are listed (Table XIX). The results of bivariate correlation analyses (Table XX) are presented and discussed with reference to the hypotheses and propositions.

The summary of bivariate analyses comprises two parts (Table XX). The first part reports on the bivariate correlations between exclusive sharing and socio-ecological factors. The second part primarily addresses the association between exclusive sharing and two types of research outcomes.

First, exclusive sharing measured by a restriction on a third-party transfer of genetic materials (i.e., sharing restriction) was associated with multiple socio-ecological factors. As posited in the first proposition (P1a and P1b), market and non-market values of genetic materials were positively associated with *sharing restriction*, but the correlations were not statistically significant. *Sharing restriction* was negatively associated with the measure on the significance of ecological conditions (P2), and the association was statistically significant ($r= -0.072$, $p<0.05$).

TABLE XIX. PROPOSITIONS AND HYPOTHESES

| Proposition | |
|---|---|
| P1a | Genetic materials with higher market value will be more likely to be shared exclusively. |
| P1b | Genetic materials with higher non-market value will be more likely to be shared exclusively. |
| P2 | Genetic materials of which ecological conditions are significant will be less likely to be shared exclusively. |
| P3 | Genetic materials obtained based on a reciprocal relationship will be less likely to be shared exclusively. |
| P4 | Genetic materials used in a commercialized research environment will be more likely to be shared exclusively. |
| **Hypothesis** | |
| H1 | Genetic materials sent to industry researchers will be more likely to be shared exclusively. |
| H2 | Genetic materials obtained from industry sources will be more likely to be shared exclusively. |
| H3 | Genetic materials obtained from abroad will be more likely to be shared exclusively. |
| H4 | Genetic materials that come with a material transfer agreement will be more likely to be shared exclusively. |
| H5 | A research project in which genetic materials are exclusively shared without a third party transfer will be less likely to produce journal publications. |
| H6 | A research project in which genetic materials are exclusively shared without a third party transfer will be more likely to produce IP-related outcomes. |

The attributes of the sharing process, sharing actors, and demand environment were found to have fairly significant associations with sharing restriction. Genetic materials obtained from abroad were positively associated with a third-party transfer restriction ($r=0.241$, $p<0.01$), which is consistent with the third hypothesis (H3). As expected (H4), the use of material transfer agreements was also positively associated with sharing restriction ($r=0.182$, $p<0.01$). However, reciprocal relationship built on the expected non-monetary returns is not negatively but instead positively associated with sharing restriction ($r=0.121$, $p<0.01$), which is contrary to the third proposition (P3).

# TABLE XX. CORRELATION MATRIX

| Variables | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Endogenous Variables** | | | | | | | | | | | |
| 1. Third-party sharing restrictions | 1.000 | | | | | | | | | | |
| 2. Publications | -0.113** | 1.000 | | | | | | | | | |
| 3. IP outcomes | 0.164** | -0.323** | 1.000 | | | | | | | | |
| **Exogenous Variables** | | | | | | | | | | | |
| 4. Market value | 0.035 | | | 1.000 | | | | | | | |
| 5. Information reliability | 0.003 | | | 0.009 | 1.000 | | | | | | |
| 6. Ecological significance | -0.072* | | | -0.071* | 0.061 | 1.000 | | | | | |
| 7. GRs obtained from abroad | 0.241** | | | 0.040 | -0.019 | 0.002 | 1.000 | | | | |
| 8. Use of MTAs | 0.182** | | | 0.048 | 0.092** | 0.037 | 0.092** | 1.000 | | | |
| 9. Expected non-monetary returns | 0.121** | | | -0.059 | 0.043 | 0.114** | 0.067* | 0.152** | 1.000 | | |
| 10.Industry sources | 0.129** | -0.299** | 0.268** | 0.292** | 0.041 | -0.092** | 0.040 | 0.100** | 0.117** | 1.000 | |
| 11. Industry recipients | 0.157** | -0.605** | 0.361** | 0.334** | 0.007 | 0.003 | 0.048 | 0.061 | 0.020 | 0.408** | 1.000 |
| 12. Commercialization | | | | | | | | | | | |
| 12-1. Development research | 0.098** | -0.240** | 0.341** | 0.173** | 0.073* | -0.063* | 0.029 | 0.010 | 0.034 | 0.337** | 0.377** |
| 12-2. Industry funding | 0.063 | -0.507** | 0.294** | 0.174** | 0.018 | 0.006 | -0.065* | 0.048 | -0.008 | 0.350** | 0.523** |
| 12-3. Industry collaborators | 0.082* | -0.368** | 0.375** | 0.177** | 0.009 | 0.023 | -0.029 | 0.100** | 0.016 | 0.484** | 0.447** |
| **Controls** | | | | | | | | | | | |
| 13. Years worked | -0.128** | | | -0.063 | -0.073* | 0.067* | 0.080* | -0.055 | -0.021 | 0.095** | -0.068* |
| 14. Log (Organization size) | 0.196** | | | 0.239** | -0.027 | -0.010 | 0.060 | 0.045 | 0.005 | 0.106** | 0.401** |
| 15. University collaborators | | 0.377** | -0.171** | | | | | | | | -0.351** |
| 16. Government collaborators | | 0.284** | -0.139** | | | | | | | | -0.221** |
| 17. Microbes | 0.076* | -0.046 | -0.007 | -0.213** | 0.053 | 0.210* | -0.016 | 0.069* | -0.161** | -0.310** | 0.014 |
| 18. Livestock | 0.088** | -0.012 | 0.138** | 0.063 | 0.008 | -0.231** | 0.040 | 0.116** | 0.157** | 0.211** | 0.099** |
| 19. Aquatics | -0.099** | 0.048 | -0.049 | 0.179** | -0.025 | -0.136** | -0.065* | -0.104** | -0.004 | 0.122** | -0.088** |
| 20. Insects | -0.114** | -0.108** | 0.039 | 0.039 | -0.064 | 0.133** | 0.050 | -0.132** | 0.053 | 0.064* | -0.044 |
| 21. Item-missings | 0.055 | 0.087** | 0.009 | 0.058 | -0.026 | 0.043 | 0.050 | 0.148** | 0.241** | 0.006 | -0.084** |

| Variables | 12-1. | 12-2. | 12-3. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Exogenous Variables** | | | | | | | | | | | |
| 11.Industry recipient | | | | | | | | | | | |
| 12. Commercialization | | | | | | | | | | | |
| 12-1. Development research | 1.000 | | | | | | | | | | |
| 12-2. Industry funding | 0.295** | 1.000 | | | | | | | | | |
| 12-3. Industry collaborators | 0.428** | 0.562** | 1.000 | | | | | | | | |
| **Controls** | | | | | | | | | | | |
| 13. Years worked | -0.015 | 0.005 | 0.070* | 1.000 | | | | | | | |
| 14. Log (Organization size) | 0.078* | 0.193** | 0.126** | -0.099** | 1.000 | | | | | | |
| 15. University collaborators | -0.192** | -0.365** | -0.304** | | | 1.000 | | | | | |
| 16. Government collaborators | -0.005 | -0.266** | -0.152** | | | -0.072* | 1.000 | | | | |
| 17. Microbes | -0.070* | 0.002 | -0.070* | -0.124** | 0.156** | 0.006 | -0.089** | 1.000 | | | |
| 18. Livestock | 0.071* | 0.052 | 0.055 | 0.025 | 0.010 | 0.068* | -0.000 | -0.518** | 1.000 | | |
| 19. Aquatics | 0.025 | -0.065* | -0.001 | -0.014 | -0.115** | -0.016 | 0.053 | -0.450** | -0.245** | 1.000 | |
| 20. Insects | -0.011 | 0.005 | 0.039 | 0.175** | -0.122** | -0.078* | 0.076* | -0.355** | -0.193** | -0.168** | 1.000 |
| 21. Item-missings | -0.130** | -0.055 | -0.104** | -0.054 | 0.031 | 0.051 | 0.048 | -0.005 | 0.031 | -0.022 | -0.006 |

** Pearson correlation is significant at the 0.01 level
* Pearson correlation is significant at the 0.05 level

Industry affiliation of both material providers (r=0.129, p< 0.01) and material receivers (r=0.157. p<0.01) was also positively associated with a third-party sharing restriction, and these associations were statistically significant. These significant and positive correlations suggest positive support for the two hypotheses on the effects of industry affiliation (H1 and H2). Additionally, all three measures of commercialization had positive associations with third-party sharing restriction. The associations of sharing restriction with development research (r=0.098, p<0.01) and industry collaborators (r=0.082, p<0.05) were both statistically significant, whereas the correlation with industry funding was not. This indicates partial support for the fourth proposition (P4).

Second, bivariate correlations with research outcomes were examined. Results showed that a third-party sharing restriction present in a project was negatively associated with publications produced in the project (r=-0.113, p<0.01). The negative correlation was statistically significant, which is in line with the fifth hypothesis (H5). On the other hand, third-party sharing restriction was positively associated with IP outcomes in a significant degree (r=0.164, p<0.01), which is consistent the expectation made in the sixth hypothesis (H6).

In sum, correlation analyses results lend preliminary support for most of the hypotheses developed in this dissertation. For instance, the results indicates positive associations between a third-party transfer restriction and industry-related variables, such as industry employment of material providers (H1) and receivers (H2), and commercialization (P4) penetrated by development research and industry collaborators. The negative association with the significance of ecological conditions was also identified (P2). As hypothesized, sharing restrictions also have positive correlations with genetic materials obtained from abroad (H3) and the use of material transfer agreements (H4). The significant correlations between sharing restriction and research outcomes were also documented, and the directions of the correlations were consistent with those hypothesized (H5 and H6).

At the same time, the correlation analysis results challenges some of expectation made in hypothesis-development. A third-party sharing restriction was significantly correlated with neither market value nor information reliability of genetic materials (P1a and P1b). Moreover, unexpectedly, instead of a positive correlation, sharing restrictions had a negative correlation with a reciprocity measure, the expected non-monetary returns (P3). Although bivariate correlation analyses are intuitive, the identified bivariate association may not hold if the other correlates are controlled for. Given the limited statistical interference in bivariate correlation analyses, multivariate analyses are necessary.

## 5.3. Probit Regression Model Estimates

Primary dependent variables of interest in this dissertation are exclusive sharing measured by a third-party sharing restriction and research outcomes. The independent effect of each variable on these dependent variables was examined with multivariate analyses. Since all three dependent variables were binary, probit regression models were employed. For the first model regarding a third-party sharing restriction, two probit regression models were run with and without multiple imputations, more specifically MICE, given the presence of missing items. For the second model on research outcomes, two probit regression models were developed to predict the likelihood of publications and intellectual property outcomes respectively.

Results from the probit models should inform us whether the hypotheses and propositions developed in this dissertation can be confirmed or rejected while controlling for other variables. The marginal effect of each factor was additionally calculated in order to better understand the magnitude of each effect on a dependent variable.

### 5.3.1. Antecedents of Exclusive Sharing

What socio-ecological factors directly influence scientists' exclusive sharing of genetic materials? This dissertation proposes four sets of antecedents that precede exclusive sharing, that is, attributes of shared objects (i.e., genetic materials), sharing actors, sharing process and demand environment. The first two probit models estimate the effects of these four sets of antecedents on exclusive sharing with and without multiple imputations (Model A and Model B in Table XXI).

TABLE XXI. PROBIT MODELS ON EXCLUSIVE SHARING

| Variables | Third-party sharing restrictions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Model A (without multiple imputations) | | | | | Model B (with multiple imputations) | | | | |
| | Probit coefficients | | Marginal effects | | P > \|t\| | Probit coefficients | | Marginal effects | | P > \|t\| |
| | Coeff. | SE | dF/dx | SE | | Coeff. | SE | dF/dx | SE | |
| Market value of GRs | -0.164 | 0.128 | -0.043 | 0.034 | 0.202 | -0.127 | 0.127 | -0.033 | 0.033 | 0.314 |
| Information reliability | -0.064 | 0.089 | -0.017 | 0.023 | 0.470 | -0.056 | 0.088 | -0.014 | 0.023 | 0.527 |
| Significance of ecological traits | -0.241 | 0.151 | -0.065 | 0.041 | 0.111 | -0.274 | 0.148 | -0.072 | 0.040 | 0.065+ |
| GRs obtained from abroad | 0.674 | 0.154 | 0.204 | 0.052 | 0.000*** | 0.733 | 0.157 | 0.220 | 0.054 | 0.000*** |
| Use of MTAs | 0.360 | 0.165 | 0.102 | 0.049 | 0.036* | 0.364 | 0.161 | 0.101 | 0.048 | 0.024* |
| Expected non-monetary returns | 0.338 | 0.186 | 0.083 | 0.042 | 0.070+ | 0.386 | 0.173 | 0.093 | 0.038 | 0.026* |
| Industry sources | 0.287 | 0.157 | 0.077 | 0.043 | 0.068+ | 0.319 | 0.148 | 0.084 | 0.040 | 0.031* |
| Industry recipients | 0.144 | 0.238 | 0.040 | 0.068 | 0.545 | 0.052 | 0.229 | 0.013 | 0.061 | 0.821 |
| Commercialization | | | | | | | | | | |
| Development research | 0.082 | 0.173 | 0.022 | 0.048 | 0.636 | 0.142 | 0.168 | 0.038 | 0.046 | 0.398 |
| Industry funding | 0.008 | 0.177 | 0.002 | 0.047 | 0.960 | -0.077 | 0.173 | -0.019 | 0.043 | 0.655 |
| Industry collaborator | -0.018 | 0.163 | -0.004 | 0.043 | 0.911 | 0.013 | 0.157 | 0.003 | 0.041 | 0.930 |
| **Controls** | | | | | | | | | | |
| Years worked | -0.018 | 0.007 | -0.005 | 0.002 | 0.015* | -0.017 | 0.007 | -0.004 | 0.001 | 0.022* |
| Organization size (logged value) | 0.109 | 0.050 | 0.029 | 0.013 | 0.010* | 0.101 | 0.052 | 0.026 | 0.013 | 0.052+ |
| Microbes | - | | | | | | | | | |
| Livestock | -0.102 | 0.209 | -0.026 | 0.053 | 0.624 | -0.137 | 0.204 | -0.034 | 0.049 | 0.502 |
| Aquatics | -0.513 | 0.235 | -0.116 | 0.045 | 0.029* | -0.451 | 0.234 | -0.101 | 0.044 | 0.054+ |
| Insects | -0.556 | 0.281 | -0.120 | 0.047 | 0.048* | -0.612 | 0.275 | -0.125 | 0.042 | 0.026* |
| Intercept | -0.989 | 0.446 | | | 0.027* | -1.090 | 0.442 | | | 0.014* |
| N | 884 (340) | | | | | 973 (367) | | | | |
| Wald $\chi^2$ (df) | 66.41 (16) | | | | | 71.41 (16) | | | | |
| Prob > $\chi^2$ | p=0.000 | | | | | P=0.000 | | | | |
| Pseudo-$R^2$ | 16.3% | | | | | 16.2% | | | | |

+p<0.10; *p<0.05; **p<0.01; ***p<0.001

### (1) Attributes of Shared Genetic Materials

As attributes of shared objects, greater market value of genetic materials is hypothesized to be positively associated with the likelihood of a third-party sharing restriction (Proposition 1a). The results of two probit regression models (Model A and Model B in Table XXI) show that this might not be the case in the study sample of this dissertation. Market value of genetic materials – measured by the basis of monetary payment made for the materials – did not have statistically significant association with a third-party sharing restriction. This indicates that market value of genetic materials did not induce exclusive sharing at some extent.

Despite recent observations which indicate the emergence of markets for genetic materials in the agricultural and bio-technology industry (Glenna et al. 2007; Stephan and Everhart 1998), a market price system for genetic materials of interest appears not to be developed fully. For this reason, monetary payments for the materials may not reflect the entire market and non-market values even though the values of the materials were perceived by researchers. The fact that approximately 70% of research projects reported using genetic materials without any charge (Table XVI) bolsters the belief that a market system for genetic materials is not absolute among agricultural scientists. The unrealistic or misrepresented market value of genetic materials could have reduced its effect size on a third-party sharing restriction.

In addition, it is plausible that researchers' decisions about whether to share genetic materials with a third party are not influenced by market value of the materials even when a market price for the materials is well-established. Agricultural scientists could be motivated by intrinsic and professional values associated with scientific discovery rather than market value (Goldberger et al. 2005; Lam 2011; Stephan and Levin 1996). Hence, the association between non-monetary values of genetic materials and exclusive sharing was examined. Higher non-market value – measured by the reliability of information attached to genetic materials – was hypothesized to be positively associated with a third-party sharing restriction (Proposition 1b). Although scientists might not care much about market value of genetic materials, the information value of genetic materials can be still critical for them to make scientific discovery (Campbell et al. 2002; Kaye et al. 2009).

Nevertheless, the results show that genetic materials with higher information reliability were not shared in an exclusive way either. This appears to challenge previous theories asserting that scientists are less willing to share when they perceive their resources to be of potential or actual value (Haeussler et al. 2009; Ipe 2003). Scientists may possess moral attitudes to generously give their materials to peers for various public outcomes, such as scientific advancement (Merton 1942), agricultural development and conservation (Glenna et al. 2007), or societal harmony (Gouldner 1960).

Yet, the results cannot be overestimated given the potential mismatch between the proposed construct and the measure. Information reliability attached to genetic materials may not fully reflect the potential and actual non-market value of genetic materials. There may still exist a wide gap between information reliability and potential scientific or industrial values given the enormous efforts to extract these field-specific values from genetic information. The novelty and rarity of genetic information would be also critical in addition to information reliability for scientists to lead scientific and industrial lead in a competitive research environment (Hilgartner and Brandt-Rauf 1994). Hence, empirical analyses with limited measures on non-market value of genetic materials do not rule out the possibility that the values of genetic materials promote exclusive sharing.

The significance of ecological conditions is posited to influence exclusive sharing. Based on socio-ecological system theory (Berkes and Folke 1998; Ostrom 2009), it is hypothesized that exclusive sharing of genetic materials is influenced not only by socio-economic values but also by the relationship between the value and ecological systems. Specifically, the significance of ecological conditions from which genetic materials were found is hypothesized to induce less exclusive sharing, while decreasing the likelihood of a third-party sharing restriction (Proposition 2). The results of probit models provide a partial evidence to support this proposition. When ecological conditions, such as geographic locations, natural environment, or natural events were considered to be important for a research project, genetic materials were more likely shared without a third-party sharing restriction (dF/dx=-0.072, p=0.065 in Model B in Table XXI). Specifically, in the probit model B using multiple imputations, when a variable of ecological conditions change its value from 0 to 1 while all the other variables are held constant, the probability of sharing restrictions decreased by 7.2% (Table XXI).

The result suggests that agricultural scientists' access to genetic materials and use patterns are contingent on ecological conditions. Given the difficulty with comprehending uncertain and complex changes in stock and flow of genetic materials in ecological systems, scientists might have been discouraged to claim exclusive rights over the materials and exclude third-parties from access to the materials. In line with previous findings on the bio-control research community (Cock et al. 2010), agricultural scientists might have self-organized a cohesive network of material users given their need to obtain various materials from multiple places in a timely manner. Nonetheless, only partial evidence was documented in one of the two probit models, so that additional assessments are required before making a conclusion.

**(2) Attributes of Sharing Processes**

The way genetic materials are shared between providers and receivers can add restrictions and obligations for any subsequent sharing with a third-party. As relevant attributes of the sharing process, proposed are three factors: cross-national sharing, formalization, and reciprocity.

First, cross-national sharing – measured by the presence of genetic materials obtained from abroad – is hypothesized to involve third-party sharing restrictions (Hypothesis 3). Findings of the probit models confirm the national border effects hypothesized. When genetic materials used in a project were obtained from other countries, US agricultural scientists in this study were more likely to encounter a third-party sharing restriction (dF/dx=0.204, $p < 0.001$ in Model A; dF/dx=0.220, $p<0.001$ in Model B in Table XXI). In fact, cross-national sharing was the strongest predictor of exclusive sharing. The presence of genetic materials from abroad increased the probability of a third-party sharing restriction by 20% to 22%, when all the other conditions were held constant.

The sharing restriction can be attributed to the substantial transaction costs required for cross-national sharing (Black and Kireeva 2010; Chen 2004; Engels and Ruschenburg 2008; Parsley and Wei 2001). Once material-providers realized these costs, they might have been discouraged from engaging in subsequent sharing with a third party. Given the multi-layered regulations on food safety, public health and conservation at the international and national levels (Black and Kireeva 2010; de Jonge 2011; Santilli 2012), material-providers can specifically ask not to transfer the materials to a third party in order to avoid regulatory burdens. Material providers can prefer to impose third-party sharing restrictions in order to maintain control over their materials given the condition where they could not oversee how the materials were used in the US. Moreover, genetic materials obtained from abroad were more likely withheld because a material receiver wanted to take a competitive advantage stemming from rare or unusual materials from abroad. Although associated motivations need to be further investigated, the positive linkage between cross-national sharing and third-party sharing restrictions appears to be evident. This finding challenges previous studies on material-sharing (Campbell et al. 2002; Lei, Juneja, and Wright 2009; Shibayama and Baba 2011; Walsh, Cohen, and Cho 2007) that focus only on domestic exchanges and do not pay attention to cross-national sharing in science.

Second, formalization accompanied by material transfer agreements (MTAs) is posited to increase the likelihood of sharing restrictions (Hypothesis 4). The positive and significant association between MTAs and sharing restrictions was found at the project-level (dF/dx=0.102, p=0.036 in Model A; dF/dx=0.101, p=0.024 in Model B in Table XXI). The use of MTAs increased the probability of a third-party sharing restriction by 10%, when all the other conditions were controlled for. This suggests that, despite their flexible applications (Barton and Siebeck 1994), MTAs were indeed used to lay out sharing restrictions instead of sharing obligations. As argued in the previous studies (Barton and Siebeck 1994; Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007), MTAs seem to serve as an effective tool that protects exclusive ownership or use rights of genetic materials in research and development.

Lastly, reciprocity – measured by the presence of non-monetary returns expected by material providers – is proposed as an attribute of the sharing process that influences subsequent sharing with a third party. Specifically, the presence of expected non-monetary returns is hypothesized to decrease the likelihood of third-party sharing restrictions (Proposition 3). Nonetheless, probit model estimates did not lend support for this proposition. Instead, positive and significant associations were documented (dF/dx=0.083, p=0.070 in Model A; dF/dx=0.093, p=0.026 in Model B in Table XXI). In other words, reciprocal relationships between material providers and receivers did not decrease but increased the likelihood of a third-party sharing restriction. The findings invite a more informed revisit to the initial proposition developed based on social capital theory (Coleman 1988; Nahapiet and Ghoshal 1998) and recent game theory of indirect reciprocity or third-party altruisms (Nowak and Sigmund 2005).

A recent work on material-sharing in science (Shibayama, Walsh, and Baba 2012) provides a valuable insight regarding the puzzling finding. Shibayama et al. (2012) argues that a reliance on bilateral or direct reciprocity between two parties crowds out a commitment to indirect reciprocity toward a third party and general reciprocity at a societal level. It interprets that the reciprocity between two parties more likely resembles a give-and-take model, whereas general reciprocity at a larger societal scale is more like a gift-giving model. So, when individuals begin to engage in bilateral reciprocation, their willingness to give their materials away to others without specific returns can decrease. Traditionally, a scientific community used to have a gift-giving model in which scientists shared their research materials with other peers not for expected tangible returns on a personal basis but for general scientific advance. However, it is argued that the norm of general reciprocity has been replaced with the norm of bilateral reciprocity, so that scientists have become more reluctant to give their genetic materials to peers without clear expectation of returns (Shibayama, Walsh, and Baba 2012).

The insight from Shibayama and colleagues' recent study (2012) helps understand why bilateral reciprocity appears to have a positive association with a third-party sharing restriction. If a subsection of the scientific community ever begins to follow the give-and-take model, the motivation for an unconditional material-transfer would decrease. Scientists would not be willing to share their materials with a third party unless the third party promises to provide reciprocal benefits to them in return. The reciprocity between two sharing actors examined in this study may resemble the Shibayama et al.'s (2012) give-and-take model of reciprocity. From this perspective, the positive association between bilateral reciprocity and third-party sharing restriction in this study can be reasonably accounted for.

### (3) Attributes of Sharing Actors and Demand Environment

As attributes of sharing actors and the demand environment, industry-related factors were examined in this dissertation. First, the industry employment of both material providers and receivers was examined as attributes of sharing actors that can influence exclusive sharing. Under the influence of companies' profit-oriented missions, reward structures and cultures (Aghion, Dewatripont, and Stein 2008;

Anderson 2000; Sauermann and Stephan 2013), industry researchers who received genetic materials would be more likely to engage in exclusive sharing without a third-party transfer of the materials (Hypothesis 1). For the same reason, it is posited that industry sources of genetic materials would be more likely to set a third-party sharing restriction (Hypothesis 2).

Probit model estimates show that the positive association between industry employment and sharing restriction is partially supported. When agricultural scientists obtained genetic materials from industry sources, the materials were likely to be shared in an exclusive way (dF/dx=0.077, p=0.068 in Model A; dF/dx=0.084, p=0.031 in Model B in Table XXI). Having industry sources increased the probability of a third-party sharing restriction by approximately 8%. Genetic materials obtained from industry sources appear not to be unconditionally available. Rather, they tend to carry a third-party sharing restriction. However, industry affiliation of material-receivers was not significantly associated with a third-party sharing restriction (p=0.545 in Model A; p=0.821 in Model B). In other words, even though genetic materials were sent to company researchers, they did not necessarily embrace a third-party sharing restriction. Findings suggest that company researchers do not withhold genetic materials and claim an exclusive use right over the materials, when they receive the materials from others. However, when company researchers send their own materials to others, industry employment did constrain a third-party transfer of genetic materials. This may indicate that industry entities tend to maintain their control over their own materials via a third-party sharing restriction once after they possess the materials in their repositories. It may also indicate the tendency that industry actors share their materials only with selected entities as a means of building confidential collaboration arrangements. In this sense, industry's selective choice of sharing partners may resemble strategic and confidential alliance (Wohlstetter, Smith, and Malloy 2005) that are often observed in the private sector.

Exclusive sharing can be influenced not only by industry actors but also by the commercialized research environment. This is because commercialized research environment incentivizes and legitimizes researchers' pursuit for private rewards and exclusive rights over genetic materials (Anderson 2000; Hessels and van Lente 2008; Rodriguez 2005). As indicators of commercialized research environment, development research, industry funding, and industry collaborators were posited to increase the likelihood of exclusive sharing (Proposition 4). Nonetheless, results show that none of the three indicators – industry funding, industry collaboration, and development research – were directly associated with exclusive sharing. Development research did not necessarily accompany more third-party sharing restrictions than basic or applied research (p=0.636 in Model A; p=0.398 in Model B). The presence of either industry funding or industry collaborators in a project was not a significant factor of a sharing restriction either.

This is contrary to previous findings showing the positive association between material-withholding and several industry-related factors, such as industry funding, interactions with industry partners, and any type of engagement in commercial activities (Blumenthal et al. 1997; Blumenthal et al. 2006; Campbell et al. 2002; McCain 1991; Murdoch and Caulfield 2009; Walsh, Cohen, and Cho 2007). Results of this study indicate that commercialization might not directly provoke exclusive sharing. However, results do not rule out a possibility that commercialization is indirectly related to sharing restrictions via material transfer agreements and other sharing attributes. In addition, a comprehensive understanding of a broader demand environment is necessary to confirm or reject the proposition. Nonetheless, findings challenge a belief that material withholding or exclusive sharing is an inevitable consequence of commercialization.

Some control variables were also found to be associated with a third-party sharing restriction. A third-party sharing restriction was negatively associated with a material receiver's number of years worked (dF/dx=-0.005, p=0.015 in Model A; dF/dx=-0.004, p=0.022 in Model B in Table XXI). As reported in previous studies (Haeussler et al. 2009; Molm, Peterson, and Takahashi 1999), professional work experiences appear to grant individual scientists more negotiation power and discretion in material-sharing and to help them to be less bound by the sharing restriction. By contrast, a material receiver's organization size was positively associated with a third-party sharing restriction (dF/dx=0.029, p=0.010 in Model A; dF/dx=0.026, p=0.052 in Model B in Table XXI). Large organizations seem to constrain individuals' material sharing with a third-party instead of encouraging it. This is contrary to the previous findings that researchers in larger organizations, particularly larger universities, are more willing to share their genetic materials (Haeussler et al., 2009). However, for government and company researchers whose activities are under stronger organizational scrutiny (Sauermann and Stephan 2013), a big organization size would mean less autonomy and more organizational control. Large organizations have greater visibility in a market and regulatory environments so that they may want to safeguard themselves against regulatory and market risk associated with material-sharing. If so, individuals in the large organizations would be more constrained regarding a third-party transfer of genetic materials. The positive association between organization size and sharing restriction suggests that organizational constraints imposed by a large organization outweigh its advantages, such as more financial and technical resources.

Lastly, a third-party sharing restriction present in a research project differs depending on the kind of organisms used in the project. Compared to projects using microbial genetic materials, projects using either aquatics or insects were less likely to have a third-party sharing restriction. This may be attributed to different legal frameworks institutionalized for each organism. Microbial genetic materials have been incorporated into the international intellectual property right protection systems such as the Trade-Related Aspects of Intellectual Property Rights (TRIPS) so that exclusive rights of inventions using microbial genetic materials are commonly granted around the world (Roffe 2008). By contrast, legal frameworks for aquatics and insects do not fully incorporate protection measures for intellectual property rights. Instead, sharing of insects (specifically honey bees) is more constrained by national regulations of animal and plant health (i.e., the Animal and Plant Health Inspection Services, APHIS). Aquatic genetic materials are more likely to be governed by emerging local industries (Long and Blackburn 2011). Findings suggest that microbial genetic materials protected by a global-wide intellectual property right system are less likely to be available to a third-party, compared to aquatics and insects governed by localized regulatory and industrial regimes.

## 5.3.2. Consequences of Exclusive Sharing on Research Outcomes

The second two probit models examined the independent effects of sharing restriction on two different research outcomes, publications (Model C) and intellectual property outcomes (Model D) as presented in Table XXII.

TABLE XXII. PROBIT MODELS ON RESEARCH OUTCOMES

| Variables | Model C (Publications) | | | | | Model D (IP Outcomes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Probit coefficients | | Marginal effects | | P > \|t\| | Probit coefficients | | Marginal effects | | P > \|t\| |
| | Coeff. | SE | dF/dx | SE | | Coeff. | SE | dF/dx | SE | |
| Third-party sharing restriction | -0.186 | 0.173 | -0.048 | 0.046 | 0.281 | 0.327 | 0.162 | 0.089 | 0.048 | 0.044* |
| **Controls** | | | | | | | | | | |
| Industry recipients/respondents | -1.312 | 0.195 | -0.412 | 0.069 | 0.000*** | 0.400 | 0.185 | 0.111 | 0.055 | 0.031* |
| Commercialization | | | | | | | | | | |
| Development research | 0.053 | 0.177 | 0.013 | 0.042 | 0.762 | 0.546 | 0.158 | 0.153 | 0.048 | 0.001** |
| Industry funding | -0.684 | 0.162 | -0.190 | 0.051 | 0.000*** | 0.048 | 0.151 | 0.012 | 0.038 | 0.749 |
| Industry collaborator | 0.049 | 0.185 | 0.012 | 0.045 | 0.789 | 0.690 | 0.148 | 0.183 | 0.043 | 0.000*** |
| University collaborator | 0.689 | 0.158 | 0.179 | 0.041 | 0.000*** | -0.080 | 0.166 | -0.020 | 0.042 | 0.627 |
| Government collaborator | 0.731 | 0.173 | 0.162 | 0.033 | 0.000*** | -0.210 | 0.152 | -0.051 | 0.035 | 0.168 |
| Microbes | | | | | | | | | | |
| Livestock | 0.153 | 0.200 | 0.036 | 0.045 | 0.443 | 0.296 | 0.197 | 0.080 | 0.057 | 0.134 |
| Aquatics | -0.041 | 0.219 | -0.010 | 0.055 | 0.852 | -0.073 | 0.255 | -0.018 | 0.061 | 0.774 |
| Insects | 0.127 | 0.229 | 0.029 | 0.051 | 0.579 | -0.524 | 0.274 | -0.107 | 0.044 | 0.056+ |
| Intercept | 0.767 | 0.191 | | | 0.000*** | -1.430 | 0.187 | | | 0.000*** |
| N | 971 (366) | | | | | 971 (366) | | | | |
| Wald $\chi^2$ (df) | 185.27 (10) | | | | | 94.42 (10) | | | | |
| Prob > $\chi^2$ | 0.000 | | | | | 0.000 | | | | |
| Pseudo-$R^2$ | 41.2% | | | | | 22.7% | | | | |

+p<0.10; *p<0.05; **p<0.01; ***p<0.001

Contrary to concerns on detrimental effects of sharing restrictions on scientific advance (Eisenberg 2006; Heller and Eisenberg 1998; Lei, Juneja, and Wright 2009), sharing restrictions imposed on genetic materials can contribute to any tangible research outcomes for those who have already gained access to the materials (Haeussler et al. 2009; Tucker 2009). The advantage of exclusive sharing on research outcomes is expected to be apparent as far as IP-related outcomes are concerned (Hypothesis 6). This is because confidential research collaboration with selected technical experts is known to be effective in producing IP outcomes (Meyer and Bhattacharya 2004). Exclusive sharing can also help diminish the risk of being defeated by competitors and losing an industrial and commercial lead (Tucker 2009). Results from the probit model (Model D in Table XXII) lend a support for the hypothesis (Hypothesis 6). A third-party sharing restriction as part of a project was positively associated with the IP outcomes produced in the project (dF/dx=0.089, p=0.044 in Model D in Table XXII). Specifically, having a third-party sharing restriction in a project increased the probability of producing IP outcomes by about 9%.

On the contrary, exclusive sharing is expected to work against the production of journal publications. This is because a third-party sharing restriction on genetic materials may hinder material receivers and their project team from developing broad research collaboration with outside members and leveraging scientific applications of the materials. Therefore, a third-party sharing restriction is hypothesized to be negatively associated with publication outcomes (Hypothesis 5). Results from the probit model (Model C in Table XXII) show that there exist the negative effects of exclusive sharing on publications, but the effects were not statistically significant (p=0.281 in Model C in Table XXII). This may be attributed to the presence of mixed effects. On one hand, sharing restriction can suppress publications by restricting research collaboration. Sharing restrictions may come with a request for publication delay. On the other hand, sharing restrictions can help a research team appreciate the scientific value of genetic materials and help them publish before other competitors do so. Yet, the positive effects of a third-party sharing restriction may not outweigh the negative effects on publications. At a minimum, increased reliance on third-party sharing restrictions appears not to foster the production of journal articles.

Overall, results show that when scientists agree on a third-party sharing restriction, the likelihood of producing intellectual property outcomes increases, while the likelihood of publishing journal articles decreases. Previous literature often contrasted private returns belonging to individuals who withhold research materials with societal costs incurred by material-withholding (Eisenberg 2006; Heller and Eisenberg 1998; Lei, Juneja, and Wright 2009; Rosenberg 1996). However, the results of this study show that the trade-offs in research outcomes exist even for those who have already obtained genetic materials. Setting a third-party sharing restriction would be a reasonable choice only when a project team pursues intellectual property outcomes. If a project team aims to publish a journal article, a third-party sharing restriction would not be useful; at a minimum, setting a sharing restriction does not increase the likelihood of producing publications.

There were significant associations between research outcomes and some control variables, as well. When genetic materials were sent to and used by a company researcher, the likelihood of publications significantly decreased (dF/dx=-0.412, p<0.001 in Model C). Having industry funding in a project also decreased the likelihood of publications produced in the project (dF/dx=-0.190, p<0.001 in Model C). At the same time, the presence of university collaborators (dF/dx=0.179, p<0.001) and government collaborators (dF/dx=0.162, p<0.001) significantly increased the likelihood of publication (Model C in Table XXII). By contrast, neither university collaborators nor government collaborators appear to play a critical role in producing IP-outcomes (Model D in Table XXII). For IP-related outcomes, the presence of industry collaborators was important (dF/dx=0.183, p<0.001 in Model D). Other industry-related factors, such as development research (dF/dx=0.048, p=0.001) and industry employment of a material receiver (dF/dx=0.055, p=0.031) were also found to increase the likelihood of producing any IP outcomes (Model D in Table XXII). These associations between research outcomes and control variables are in line with previous findings about the influence of different missions and incentive structures institutionalized in university, government, and industry settings (Aghion, Dewatripont, and Stein 2008; Buenstorf 2009; Sauermann and Stephan 2013).

## **5.4. Structural Model Estimates**

The conceptual model of this study proposes a sequential process in which exclusive sharing predicted by it antecedents, in turn, influences research outcomes. The proposed sequential process can be briefly described as a two-stage as follows:

Equation 1: Exclusive Sharing = f (Shared Objects, Sharing Process, Material Providers and Receivers, Research Environment, Controls)

Equation 2: Research Outcomes = f (Exclusive Sharing, Material Receivers, Research Environment, Controls)

In other words, exclusive sharing is proposed to be endogenous in that it is predicted by a set of antecedents and also predicts the likelihood of producing research outcomes. The following section examines the linkage between two equations on exclusive sharing and research outcomes and discusses the need to consider a structural model that simultaneously estimates the two equations. Then, the estimates of structural models, particularly path models, are reported; they include 1) the direct effects on exclusive sharing, 2) the direct effects on research outcomes, and 3) the indirect effects on research outcomes occurred via exclusive sharing.

### 5.4.1. Endogeneity of Exclusive Sharing

Multiple techniques and tests have been developed to assist informing the decision of whether to violate independence assumptions built in most of regression analyses; they include a two-stage residual inclusion, a two-stage predictor inclusion, and the Hausman test (Wooldridge 2002). The basic idea behind these tests is to check whether not only an endogenous variable, X, but also the residual term of the variable, X, change the prediction of an outcome variable, Y (Schroeder 2010). Suppose that X is predicted by a set of antecedents, X1 and X2, while it is again used to predict the outcome variable, Y. In this case, the variable X is considered to be endogenous in the full model predicting Y when the residual term of X (an error term which is not explained by X1 and X2 in the first equation) is significantly associated with the outcome variable, Y. Nonetheless, a challenge arises when the variable X is binary so that its residual term is not observable (Bollen, Guilkey, and Mroz 1995). When binary variables and binary latent variables are suspected to be endogenous, indirect ways to gauge the error terms of variables needs to be incorporated into the prediction. One way of dealing with the issue is a two-stage probit least squares approach (Timpone 2003). It considers the binary variable, X, to be generated from an unobserved (latent) continuous index function, which produce ‘z’ scores on this unobserved continuum. Based on this transformation, an error term of the variable X*, essentially the latent continuous index variable, is obtained and used to check whether the error term is associated with an outcome variable Y. In this study, *a third-party sharing restriction (i.e., sharing restriction)* is proposed to be a binary endogenous variable (i.e., whether to have a third-party sharing restriction), so a two-stage probit model was used to test whether the error term of exclusive sharing is associated with the error terms of research outcome variables.

Furthermore, the variable of a sharing restriction is a single instrument which is predicted by a set of antecedents and also used to predict research outcomes. Therefore, *sharing restriction* can be considered as a endogenous regressor in a two-step probit model (Schroeder 2010). All the variables included in the probit model predicting the likelihood of sharing restriction were used as instrumental variables and the latent z-index of *sharing restriction* was used to predict the likelihood of research outcomes, both in the form of publications and intellectual property (Table XXIII).

The Wald test of exogeneity for a model with a binary outcome variable (Bollen, Guilkey, and Mroz 1995) was conducted to check whether the error term of *sharing restriction* is significantly associated with the error term of *research outcomes*. If the correlation (i.e., arthrho) between the error term of *sharing restriction* and the error term of *research outcomes* is statistically significant, the null hypothesis of exogeneity is rejected. This suggests that researchers need to take into account the endogeneity of the regressor in a full model (Wooldridge 2002).

As shown in Table XXIII, the results indicate that the error term of *sharing restriction* is significantly correlated with the error term of *intellectual property outcomes* (r=-0.341, p=0.048), so the null hypothesis of exogeneity is rejected (p=0.047). This indicates that the first equation on sharing restriction can be a part of the second equation predicting IP outcomes. On the other hand, the results show that the error term of *sharing restriction* is not significantly associated with the error term of *publication outcomes* (Table XXIII). In other words, there exists a structural disconnection between two models predicting a sharing restriction and publication outcomes.

TABLE XXIII. PROBIT MODEL WITH ENDOGENOUS REGRESSOR

| Variables | Publications | | | IP Outcomes | | |
|---|---|---|---|---|---|---|
| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| |
| Third-party sharing restriction | -0.579 | 0.451 | 0.199 | 0.327 | 0.162 | 0.044 |
| Industry recipients/respondents | -1.183 | 0.181 | 0.000 | 0.400 | 0.185 | 0.031 |
| Commercialization | | | | | | |
| Development research | -0.036 | 0.146 | 0.803 | 0.546 | 0.158 | 0.001 |
| Industry funding | -0.611 | 0.151 | 0.000 | 0.048 | 0.151 | 0.749 |
| Industry collaborator | 0.053 | 0.158 | 0.735 | 0.690 | 0.148 | 0.000 |
| University collaborator | 0.696 | 0.131 | 0.000 | -0.080 | 0.166 | 0.627 |
| Government collaborator | 0.775 | 0.140 | 0.000 | -0.210 | 0.152 | 0.168 |
| Microbes | | | | | | |
| Livestock | 0.158 | 0.148 | 0.284 | 0.296 | 0.197 | 0.134 |
| Aquatics | -0.014 | 0.181 | 0.935 | -0.073 | 0.255 | 0.774 |
| Insects | 0.155 | 0.223 | 0.486 | -0.524 | 0.274 | 0.056 |
| Intercept | 0.800 | 0.167 | 0.000 | -1.430 | 0.187 | 0.000 |
| Insigma | -0.970 | 0.023 | 0.000 | -0.969 | 0.023 | 0.000 |
| Athrho | 0.153 | 0.188 | 0.417 | -0.341 | 0.172 | 0.048 |
| Sigma | 0.378 | 0.009 | | 0.379 | 0.009 | |
| Rho | 0.152 | 0.184 | | -0.326 | 0.153 | |
| **Wald test of exogeneity** (/athrho=0) | | | | | | |
| N | 884 | | | 884 | | |
| $\chi^2$ (1) | 0.66 | | | 3.93 | | |
| Prob > $\chi^2$ | 0.417 | | | 0.047 | | |

**Instrumented:** Third-party sharing restriction

**Instruments**: Market value, information reliability, significance of ecological conditions, GRs obtained from abroad, Use of MTAs, Expected non-monetary returns, Industry sources, Industry recipients, Development research, Industry funding, Industry collaborators, Years worked, Organization size, Livestock, Aquatics, and Insects

Similar results are also found in the endogeneity test in a seemingly unrelated probit model (Table XXIII). When the two equations on exclusive sharing and research outcomes were simultaneously estimated, the error term of *sharing restriction* is significantly correlated with the error term of *intellectual property outcomes* (r=-0.175, p=0.094). However, the error term of *sharing restriction* is not significantly associated with the error term of *publication outcomes* (Table XXIII).

Overall, the results suggest that the sequential process proposed in the study can be appropriate to describe empirical observations on IP outcomes but not publication outcomes. The difference between IP outcomes and publication outcomes, in terms of their linkages with an exclusive sharing process, may reflect two divergent production systems institutionalized in science. Intellectual property rights can be more directly linked with exclusive sharing, secrecy and material-withholding, whereas publications are more likely realized by open disclosure and discussion instead of exclusive sharing. Nonetheless, the results also show that exclusive sharing process may not be associated with publication production process at all. Even though science production systems have been built upon an open science institution (Merton 1942; Polanyi 1962) and several measures have been institutionalized to mandate open sharing of research materials for publications (Marshall 1998; McCain 1995; Stern 2004), exclusive sharing prior to publications might not  be penalized as might be expected. Researchers may not encounter substantial barriers in expanding their research collaboration even when they agree with a third-party sharing restriction. It is also possible that individual scientists co-opt with institutional changes and devise a hybrid strategy to pursue publications without passing their materials to a third-party (Murray 2011).

What seems obvious, though, is that a typical science production system based on open sharing is not as effective as might be expected. As previous studies (Haas and Park 2010; Mitroff 1974; Tucker 2009) point out, individual motivation to garner and withhold research materials for one’s own discoveries can weaken the institutionalized linkage between sharing patterns and publication outcomes. It is also possible that intensified proprietary institutions and intellectual property production systems create an alternative way of publishing articles, such as patent-paper pairs (Murray 2002; Van Looy, Callaert, and Debackere 2006); this may indirectly influence the way in which material-sharing patterns are linked with publications. Findings on publications call for further investigation into the mechanism by which exclusive sharing comes apart from publication production systems.

## 5.4.2. Structural Model Estimates

Given the identified structural disconnection between an exclusive sharing process and publication production process, structural models linking exclusive sharing and research outcomes were developed only for predicting IP outcomes. Structural equation modeling, particularly a path model, was used to investigate the effects of endogenous as well as exogenous variables on IP outcomes. Structural models were run with and without multiple imputations for missing data (Table XXIV, Figure 8 and Figure 9). The structural model assesses the path through which socio-ecological factors are associated with a third-party sharing restriction, which in turn influences IP outcomes.

Model test statistics suggest that the structural models developed in this dissertation are correspondent well with the sample data. As an original fit statistic, a chi-square test of "exact-fit-hypothesis" is commonly used to examine whether the model well corresponds with data (Kline 2005). In both structural models, the chi-square tests did not reject the "exact-fit-hypothesis" ($\chi_M^2$ ($df_M$) = 16.71 (11), p=0.116 in Model I; $\chi_M^2$ ($df_M$) = 14.93 (11), p=0.185 in Model II). This means that the model-implied covariance matrix was identical to the covariance matrix of the sample/population.

As alternative fit indices, a Root Mean Square Error of Approximation (RMSEA) and a Comparative Fit Index (CFI) were also examined. Unlike a chi-square test, both RMSEA and CFI do not necessarily favor models with a large sample size (Kline 2005). RMSEA is an absolute scale assessing the badness-of-fit of the model. A value of zero indicates the best-fit, a value of 0.05 indicates a close-fit, and a value over 0.10 indicates a poor-fit (Kline 2005; Browne and Cudeck 1993). The RMSEA scales of the structural models in this dissertation do not exceed 0.05 (0.024 in Model I; 0.019 in Model II in Table XXIV), which indicates a good-fit of the models. A CFI is a comparative index evaluating the relative improvement of the fit of the researchers' model over that of a baseline model (Kline 2005, p208). If a CFI reaches 1.0, it means the model used by researchers explains the data better than the baseline model does. If a CFI is larger than 0.90, the model is considered to be acceptable. The CFIs of the two models are over 0.90 (0.909 in Model I; 0.941 in Model II), which indicates that the exploratory power of the models is greater than the one of the baseline models is.

In addition, the model fit statistics included a pseudo-R-squared. A pseudo-R-squred is developed based on the information on how much variance of latent variables – proxy residual variables in probit models – is explained by the model used (McKelvey and Zavoina 1975; Snijers and Bosker 1994). Although these figures are not precisely equivalent to a R-squared in an ordinary least square regression, the higher value of pseudo-R-squareds shows that more variance was explained by the structural models than the probit regression models in this study. The pseudo-R-squareds of the equation predicting a third-party sharing restriction ranged around 30% in Model I and II which was higher than 16% in the probit models (Table XXI). The pseudo-R-squareds of the equation predicting IP outcomes were approximately 36% in both structural models which was higher than 23% in the probit model on IP outcomes (Table XXII). Figure 8 and Figure 9 present a visual summary of the results of Model I and Model II respectively.

TABLE XXIV. STRUCTURAL MODELS I AND II ON EXCLUSIVE SHARING AND IP OUTCOMES

| Variables | Structural Model I (without multiple imputations) | | | | | | Structural Model II (with multiple imputations) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Third-party sharing restrictions | | | IP outcomes | | | Third-party sharing restrictions | | | IP outcomes | | |
| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| |
| **Endogenous variables** | | | | | | | | | | | | |
| Third-party sharing restrictions | | | | 0.201 | 0.081 | 0.013* | | | | 0.186 | 0.077 | 0.016* |
| **Exogenous variables** | | | | | | | | | | | | |
| Market value of GRs | -0.138 | 0.130 | 0.288 | | | | -0.118 | 0.129 | 0.359 | | | |
| Information reliability | -0.056 | 0.087 | 0.517 | | | | -0.048 | 0.085 | 0.572 | | | |
| Significance of ecological traits | -0.277 | 0.152 | 0.068+ | | | | -0.295 | 0.148 | 0.046* | | | |
| GRs obtained from abroad | 0.621 | 0.153 | 0.000*** | | | | 0.689 | 0.151 | 0.000*** | | | |
| Use of MTAs | 0.429 | 0.160 | 0.007** | | | | 0.439 | 0.154 | 0.004** | | | |
| Expected non-monetary returns | 0.305 | 0.205 | 0.137 | | | | 0.377 | 0.189 | 0.047* | | | |
| Industry sources | 0.297 | 0.176 | 0.092+ | | | | 0.323 | 0.168 | 0.054+ | | | |
| Industry recipients | 0.172 | 0.242 | 0.478 | 0.391 | 0.233 | 0.094+ | 0.070 | 0.237 | 0.769 | 0.427 | 0.226 | 0.059+ |
| Commercialization | | | | | | | | | | | | |
| Development research | 0.043 | 0.183 | 0.821 | 0.723 | 0.172 | 0.000*** | 0.121 | 0.175 | 0.491 | 0.568 | 0.161 | 0.000** |
| Industry funding | 0.062 | 0.177 | 0.725 | -0.015 | 0.184 | 0.934 | -0.044 | 0.175 | 0.801 | 0.028 | 0.168 | 0.866 |
| Industry collaborator | -0.002 | 0.202 | 0.992 | 0.605 | 0.188 | 0.001** | 0.027 | 0.193 | 0.887 | 0.641 | 0.172 | 0.000*** |
| **Controls** | | | | | | | | | | | | |
| Years worked | -0.019 | 0.008 | 0.023* | | | | -0.018 | 0.008 | 0.027* | | | |
| Organization size (logged value) | 0.117 | 0.051 | 0.021* | | | | 0.101 | 0.051 | 0.050+ | | | |
| University collaborators | | | | -0.025 | 0.194 | 0.896 | | | | -0.071 | 0.176 | 0.685 |
| Government collaborators | | | | -0.296 | 0.177 | 0.094+ | | | | -0.291 | 0.162 | 0.072+ |
| Microbes | - | | | - | | | - | | | - | | |
| Livestock | -0.128 | 0.201 | 0.523 | 0.350 | 0.261 | 0.180 | -0.156 | 0.197 | 0.429 | 0.268 | 0.247 | 0.278 |
| Aquatics | -0.559 | 0.245 | 0.022* | 0.027 | 0.303 | 0.930 | -0.476 | 0.244 | 0.051+ | 0.016 | 0.279 | 0.954 |
| Insects | -0.595 | 0.321 | 0.064+ | -0.188 | 0.279 | 0.502 | -0.638 | 0.316 | 0.044* | -0.302 | 0.266 | 0.256 |
| Thresholds | 1.106 | 0.479 | 0.021* | 1.768 | 0.466 | 0.000*** | 1.169 | 0.461 | 0.011* | 1.158 | 0.452 | 0.000*** |
| **Model fit indices** | | | | | | | | | | | | |
| Pseudo-$R^2$ | 30.2% | | | 36.7% | | | 29.8% | | | 35.9% | | |
| N | 884 (340) | | | 884 (340) | | | 973 (367) | | | 971 (366) [a] | | |
| $\chi_M^2$ ($df_M$) | 16.71 (11), p=0.116 | | | | | | 14.93 (11), p=0.185 | | | | | |
| MSEA (90% CI) | 0.024 (0.000 - 0.046) | | | | | | 0.019 (0.000 - 0.041) | | | | | |
| CFI | 0.909 | | | | | | 0.941 | | | | | |
| $\chi_B^2$ ($df_B$) | 99.58 (37) | | | | | | 103.84 (37) | | | | | |

[a] Item-missings in response on intellectual property (IP) outcomes were not imputed; +p<0.10; *p<0.05; **p<0.01; ***p<0.001

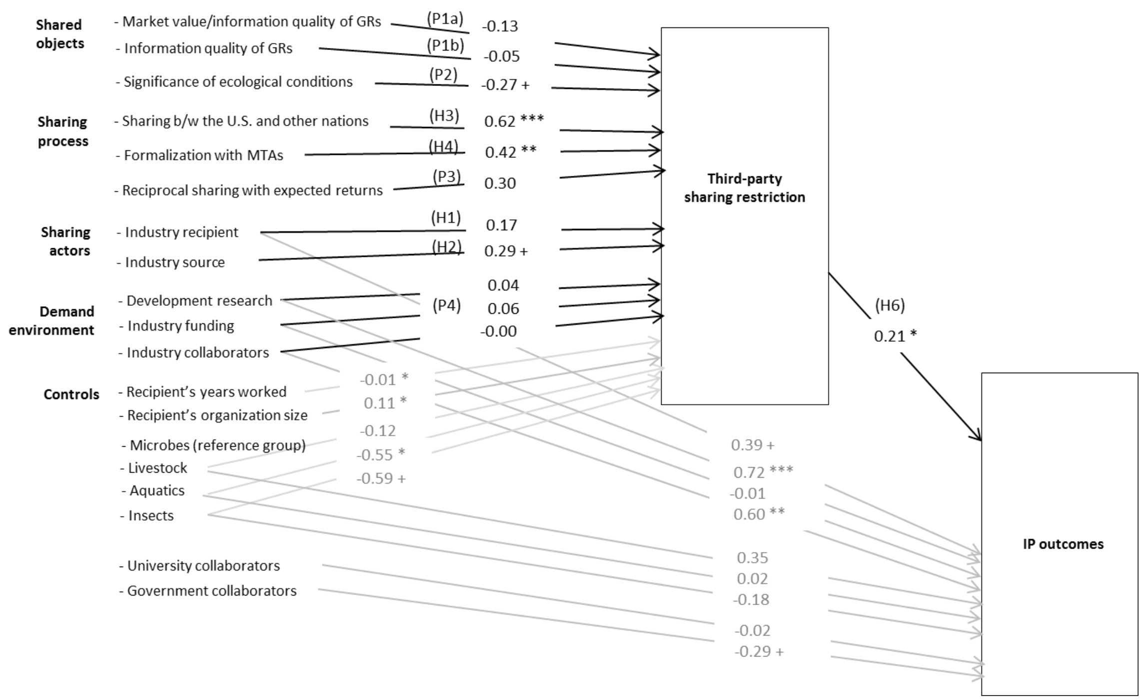


Figure 8. Structural Model I without MI on Exclusive Sharing and IP Outcomes

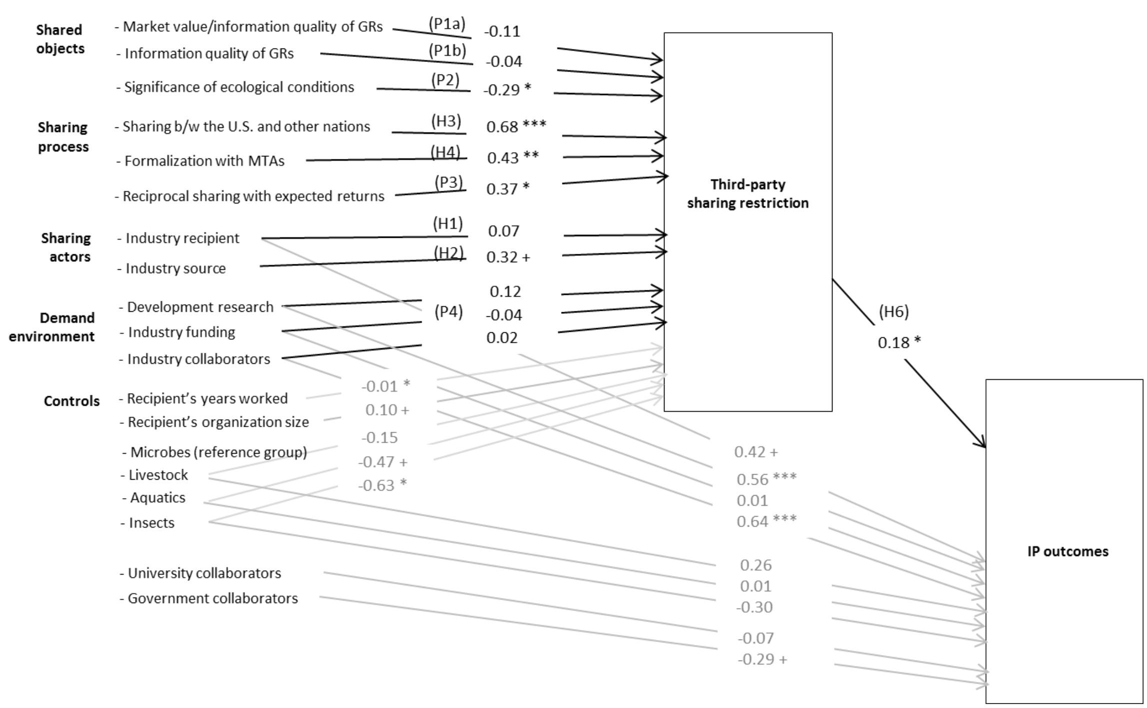


Figure 9. Structural Model II with MI on Exclusive Sharing and IP Outcomes

**<u>(1) Direct Effects on Exclusive Sharing</u>**

The first equation in each structural equation model estimates the direct effects of each socio-ecological factor on exclusive sharing (Table XXIV). The results of structural models are fairly consistent with the results of probit models as explained in the previous section (Section 5.3.1).

As the attributes of shared objects, greater market value and the information reliability of genetic materials are hypothesized to be positively associated with the likelihood of a third-party sharing restriction (Proposition 1a and 1b). However, neither market value nor the information reliability of genetic materials was found to have significant associations with a third-party sharing restriction. On the other hand, the significance of ecological conditions was found to influence a third-party sharing restriction in both structural models (coeff.= -0.277, p=0.068 in Model I; coeff.=-0.295, p=0.046 in Model II), which supports the second proposition (Proposition 2). When a project researcher reported significant ecological conditions from which genetic materials were found, the materials were less likely to carry a third-party sharing restriction. This suggests that scientists' reliance on a complex and uncertain environment for access to genetic materials may limit their control over genetic materials and prevent material-withholding from a third-party.

As the attributes of the sharing process, cross-national sharing is hypothesized to promote exclusive sharing (Hypothesis 3). Structural model results support the hypothesis in that cross-national sharing was one of the strongest predictor of a third-party sharing restriction (coeff.=0.621, p<0.001 in Model I; coeff.=0.689, p<0.001 in Model II). This indicates the presence of substantial border effects limiting scientists' access to genetic materials. As expected (Hypothesis 4), formalized sharing using material transfer agreements was found more likely to carry a third-party sharing restriction (coeff.=0.429, p=0.007 in Model I; coeff.=0.439, p=0.004 in Model II). This shows that material transfer agreements were indeed used to lay out sharing restrictions instead of mandating material-sharing. Unlike the initial expectation (Proposition 3), the positive association between bilateral reciprocity and sharing restrictions was also found in one of the structural models (coeff.=0.189, p= 0.047 in Model II in Table XXIV), in addition to the probit regression models (Table XXI). This appears to support Shibayama et al.'s (2012) argument that bilateral reciprocation diminishes one's willingness to make a generous offer to a third party or the unknown public without a specific expectation of returns.

In addition, industry employment of sharing actors is posited to facilitate exclusive sharing (Hypotheses 1and 2), but the positive association between industry employment and a third-party sharing restriction was found only when industry entities were material-providers (coeff.=0.297, p=0.092 in Model I; coeff=0.323, p=0.054 in Model II in Table XXIV). Industry employment of material receivers appears not to be associated with the likelihood of sharing restrictions. Commercialization of the research environment, measured by three items (i.e., industry funding, industry collaborators, and development research), was not found to increase the likelihood of a sharing restriction either.

#### **(2) Direct and Indirect Effects on IP Outcomes**

The second equation of the structural models predicts the likelihood of producing intellectual property outcomes (Table XXIV). Similar to the findings of probit models, a third-party sharing restriction has a direct positive effect on intellectual property (IP) outcomes (coeff.=0.201, p=0.013 in Model I; coeff.=0.186, p=0.016 in Model II), which supports the sixth hypothesis (H6). As anticipated, exclusive sharing among selected entities can help project members appreciate the scientific and industrial values of the materials without getting scooped.

Direct effects of control variables are also documented. When genetic materials were obtained and used by industry researchers in a project, IP outcomes were more likely to be produced in the project (coeff.=0.391, p=0.094 in Model I; coeff.=0.427, p=0.059 in Model II). Commercialization of the research environment was not directly associated with exclusive sharing but directly associated with IP outcomes; specifically, having industry collaborators in a project significantly increased the likelihood of producing intellectual property outcomes in the project (coeff.=0.605, p=0.001 in Model I; coeff.=0.641, p<0.001 in Model II). Development research was also more likely to produce intellectual property outcomes (coeff.= 0.723, p<0.001 in Model I; coeff.=0.568, p<0.001 in Model II). On the other hand, the presence of government collaborators was found to decrease the likelihood of IP outcomes (coeff.=-0.296, p=0.094 in Model I; coeff.=-0.291, p=0.072 in Model II).

Based on the structural linkage between exclusive sharing and IP outcomes, socio-ecological factors directly influencing exclusive sharing are seen to indirectly influence IP outcomes. Table XXV re-specifies direct, indirect and total effects on IP outcomes in each structural model presented in Table XXIV. As shown in Table XXV, formalized sharing based on material transfer agreements (MTAs) was found to create a third-party sharing restriction, thus increasing the likelihood of producing IP outcomes in an indirect way (coeff.=0.086, p=0.059 in Model I; coeff.=0.082, p=0.060 in Model II). In a similar fashion, cross-national sharing was found to increase sharing restrictions and, in turn, increase the likelihood of IP outcomes (coeff.=0.125, p=0.032 in Model I; coeff.=0.128, p=0.029 in Model II). On the other hand, the indirect effects of other socio-ecological factors, such as the significance of ecological conditions, bilateral reciprocity, and industry sources, were found not to be statistically significant. The lack of statistical power can be attributed to the small magnitude of the direct effects of these socio-ecological factors on sharing restrictions and the moderate level of the direct effect of sharing restrictions on IP outcomes.

The total effect of each factor on IP outcomes was calculated by summing up its direct and indirect effects. Overall, commercialization of the research environment and industry employment of material-receivers were the strongest direct predictors of IP outcomes. In addition, broader socio-ecological settings of material-sharing (i.e., cross-national sharing, and formalized sharing with MTAs) were found to indirectly influence the production of IP outcomes by creating a third-party sharing restriction.

TABLE XXV. STRUCTURAL MODELS I AND II: DIRECT, INDIRECT, AND TOTAL EFFECTS

| Variables | Intellectual Property (IP) Outcomes | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Structural Model I (without multiple imputations) | | | | | | | | | Structural Model II (with multiple imputations) | | | | | | | | |
| | Indirect Effects | | | Direct Effects | | | Total Effects | | | Indirect Effects | | | Direct Effects | | | Total Effects | | |
| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| |
| **Endogenous variables** | | | | | | | | | | | | | | | | | | |
| Third-party sharing restrictions | | | | 0.201 | 0.081 | 0.013* | 0.201 | 0.081 | 0.013* | | | | 0.186 | 0.077 | 0.016* | 0.186 | 0.077 | 0.016* |
| **Exogenous variables** | | | | | | | | | | | | | | | | | | |
| Market value of GRs | -0.028 | 0.029 | 0.346 | | | | -0.028 | 0.029 | 0.346 | -0.022 | 0.026 | 0.405 | | | | -0.022 | 0.026 | 0.405 |
| Information reliability | -0.011 | 0.018 | 0.529 | | | | -0.011 | 0.018 | 0.529 | -0.009 | 0.016 | 0.583 | | | | -0.009 | 0.016 | 0.583 |
| Significance of ecological traits | -0.056 | 0.038 | 0.141 | | | | -0.056 | 0.038 | 0.141 | -0.055 | 0.035 | 0.120 | | | | -0.055 | 0.035 | 0.120 |
| GRs obtained from abroad | 0.125 | 0.058 | 0.032* | | | | 0.125 | 0.058 | 0.032* | 0.128 | 0.059 | 0.029* | | | | 0.128 | 0.059 | 0.029* |
| Use of MTAs | 0.086 | 0.046 | 0.059+ | | | | 0.086 | 0.046 | 0.059+ | 0.082 | 0.043 | 0.060+ | | | | 0.082 | 0.043 | 0.060+ |
| Expected non-monetary returns | 0.061 | 0.047 | 0.192 | | | | 0.061 | 0.047 | 0.192 | 0.070 | 0.045 | 0.120 | | | | 0.070 | 0.045 | 0.120 |
| Industry sources | 0.060 | 0.040 | 0.132 | | | | 0.060 | 0.040 | 0.132 | 0.060 | 0.037 | 0.102 | | | | 0.060 | 0.037 | 0.102 |
| Industry recipients | 0.035 | 0.053 | 0.516 | 0.391 | 0.233 | 0.094+ | 0.425 | 0.243 | 0.081+ | 0.013 | 0.046 | 0.777 | 0.427 | 0.226 | 0.059+ | 0.440 | 0.234 | 0.060+ |
| Commercialization | | | | | | | | | | | | | | | | | | |
| Development research | 0.009 | 0.037 | 0.812 | 0.723 | 0.172 | 0.000*** | 0.731 | 0.174 | 0.000*** | 0.022 | 0.033 | 0.496 | 0.568 | 0.161 | 0.000*** | 0.590 | 0.162 | 0.000*** |
| Industry funding | 0.013 | 0.035 | 0.724 | -0.015 | 0.184 | 0.934 | -0.003 | 0.185 | 0.988 | -0.008 | 0.033 | 0.803 | 0.028 | 0.168 | 0.866 | 0.020 | 0.169 | 0.905 |
| Industry collaborator | 0.000 | 0.041 | 0.992 | 0.605 | 0.188 | 0.001** | 0.605 | 0.191 | 0.002** | 0.005 | 0.036 | 0.888 | 0.641 | 0.172 | 0.000*** | 0.646 | 0.174 | 0.000*** |
| **Controls** | | | | | | | | | | | | | | | | | | |
| Years worked | -0.004 | 0.002 | 0.119 | | | | -0.004 | 0.002 | 0.119 | -0.003 | 0.002 | 0.125 | | | | -0.003 | 0.002 | 0.125 |
| Organization size (logged value) | 0.024 | 0.013 | 0.078+ | | | | 0.024 | 0.013 | 0.078+ | 0.019 | 0.012 | 0.110 | | | | 0.019 | 0.012 | 0.110 |
| University collaborators | | | | -0.025 | 0.194 | 0.896 | -0.025 | 0.194 | 0.896 | | | | -0.071 | 0.176 | 0.685 | -0.071 | 0.176 | 0.685 |
| Government collaborators | | | | -0.296 | 0.177 | 0.094+ | -0.296 | 0.177 | 0.094+ | | | | -0.291 | 0.162 | 0.072+ | -0.291 | 0.162 | 0.072+ |
| Microbes | - | | | - | | | | | | - | | | - | | | | | |
| Livestock | -0.026 | 0.041 | 0.534 | 0.350 | 0.261 | 0.180 | 0.325 | 0.260 | 0.212 | -0.029 | 0.039 | 0.453 | 0.268 | 0.247 | 0.278 | 0.239 | 0.245 | 0.330 |
| Aquatics | -0.112 | 0.066 | 0.091+ | 0.027 | 0.303 | 0.930 | -0.086 | 0.285 | 0.763 | -0.088 | 0.060 | 0.142 | 0.016 | 0.279 | 0.954 | -0.072 | 0.265 | 0.785 |
| Insects | -0.120 | 0.079 | 0.132 | -0.188 | 0.279 | 0.502 | -0.307 | 0.296 | 0.298 | -0.118 | 0.076 | 0.119 | -0.302 | 0.266 | 0.256 | -0.421 | 0.283 | 0.137 |
| **Model fit indices** | | | | | | | | | | | | | | | | | | |
| Pseudo-$R^2$ | 36.7% | | | | | | | | | 35.9% | | | | | | | | |
| N | 884 (340) | | | | | | | | | 971 (366) [a] | | | | | | | | |
| $\chi_M^2$ ($df_M$) | 16.71 (11), p=0.116 | | | | | | | | | 14.93 (11), p=0.185 | | | | | | | | |
| RMSEA (90% CI) | 0.024 (0.000 - 0.046) | | | | | | | | | 0.019 (0.000 - 0.041) | | | | | | | | |
| CFI | 0.909 | | | | | | | | | 0.941 | | | | | | | | |
| $\chi_B^2$ ($df_B$) | 99.58 (37) | | | | | | | | | 103.84 (37) | | | | | | | | |

[a] Item-missings in response on intellectual property (IP) outcomes were not imputed; +p<0.10; *p<0.05; **p<0.01; ***p<0.001

### (3) An Alternative Model: Direct and Indirect Effects on IP Outcomes

The results reported in Table XXV are informative to assess the unintended as well as the intended consequences of socio-ecological settings on IP outcomes. Nonetheless, the results need to be carefully interpreted because the structural models of this dissertation take into account only the indirect effects of socio-ecological factors on IP outcomes realized via exclusive sharing. It is possible that socio-ecological factors are mediated not only by exclusive sharing patterns but also by other social phenomena. It is also possible that socio-ecological factors directly influence the production of IP outcomes. Although the direct association between socio-ecological conditions and IP outcomes without being mediated by exclusive sharing is beyond the scope of this study, an exploratory analysis was additionally conducted in order to better understand the broad context in which the material-sharing process is linked with IP production.

As shown in Table XXVI, alternative models (Model III and Model IV) incorporated both the direct as well as indirect effects of socio-ecological factors on IP outcomes. The results improve understanding of the relative magnitude of indirect effects realized via exclusive sharing, when compared to their direct effects of socio-ecological factors on IP outcomes. Most of the findings for the direct effects on IP outcomes are quite similar to those of the structural models I and II presented in this study (Table XXV). However, the positive indirect effect of cross-national sharing was off-set by its negative direct effects on IP outcomes. Hence, the total effect of cross-national sharing was found not to have significant association with IP outcomes. This suggests that there exist fundamental barriers in transforming genetic materials from abroad into intellectual property related outcomes, even though sharing restrictions accompanied by foreign genetic materials often preconditions the production of IP outcomes. As reported by previous studies, geographic distance (Chen 2004; Parsley and Wei 2001), regulatory constraints (Evans 2003; Turrini and van Ypersele 2010), and informal barriers resulting from different languages and cultures (Huchet-Bourdon and Cheptea 2011; Olper and Raimondi 2008) can directly decrease the effectiveness of IP production. It is also possible that political and ethical concerns on bio-piracy or inappropriate bio-prospecting (Polski 2005) limit the possibility that genetic materials from abroad are directly used for intellectual property outcomes.

In contrast, formalized sharing based on material transfer agreements (MTAs) was found to be rather directly associated with IP outcomes. The presence of MTAs directly increased the likelihood of producing IP outcomes (coeff.=0.565, p=0.002 in Model III; coeff.=0.546, p=0.001 in Model IV), so that the positive association between MTAs and IP outcomes become more apparent in the alternative models (Table XXVI), when compared to the structural models I and II presented in the previous section (Table XXV). This suggests that MTAs were used not just to stipulate a third-party sharing restriction but also to directly precondition the production of IP outcomes. As reported by a couple of previous studies (Barton and Siebeck 1994; Ghijsen 2009), MTAs can be intensively used for the exclusive appreciation of industrial and commercial values coming from genetic materials, especially when the commercial value of the materials is not recognized so it is not well protected by existing legal instruments.

In sum, the alternative structural models suggest that the total effects of cross-national sharing on IP outcomes can be weakened, whereas the total effects of MTAs can be strengthened if both their direct and indirect effects on IP outcomes are considered.

TABLE XXVI. ALTERANTIVE STRUCTURAL MODELS III AND IV: DIRECT, INDIRECT, AND TOTAL EFFECTS ON IP OUTCOMES

| Variables | Intellectual Property (IP) outcomes | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Structural Model III (without multiple imputations) | | | | | | | | | Structural Model IV (with multiple imputations) | | | | | | | | |
| | Indirect Effects | | | Direct Effects | | | Total Effects | | | Indirect Effects | | | Direct Effects | | | Total Effects | | |
| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| | Coeff. | SE | P > \|t\| |
| **Endogenous variables** | | | | | | | | | | | | | | | | | | |
| Third-party sharing restrictions | | | | 0.180 | 0.092 | 0.050+ | 0.180 | 0.092 | 0.050+ | | | | 0.158 | 0.088 | 0.071+ | 0.158 | 0.088 | 0.071+ |
| **Exogenous variables** | | | | | | | | | | | | | | | | | | |
| Market value of GRs | -0.026 | 0.028 | 0.348 | 0.039 | 0.122 | 0.751 | 0.012 | 0.124 | 0.920 | -0.018 | 0.024 | 0.437 | -0.010 | 0.121 | 0.931 | -0.029 | 0.121 | 0.811 |
| Information reliability | -0.012 | 0.016 | 0.449 | 0.082 | 0.096 | 0.391 | 0.070 | 0.098 | 0.477 | -0.009 | 0.014 | 0.517 | 0.069 | 0.095 | 0.468 | 0.060 | 0.097 | 0.538 |
| Significance of ecological traits | -0.049 | 0.038 | 0.197 | -0.054 | 0.176 | 0.757 | -0.103 | 0.173 | 0.552 | -0.046 | 0.035 | 0.186 | -0.035 | 0.161 | 0.827 | -0.081 | 0159 | 0.610 |
| GRs obtained from abroad | 0.117 | 0.065 | 0.071+ | -0.138 | 0.155 | 0.372 | -0.021 | 0.155 | 0.891 | 0.114 | 0.066 | 0.087+ | -0.152 | 0.153 | 0.321 | -0.038 | 0.152 | 0.802 |
| Use of MTAs | 0.060 | 0.042 | 0.158 | 0.565 | 0.178 | 0.002** | 0.625 | 0.170 | 0.000*** | 0.055 | 0.039 | 0.164 | 0.546 | 0.164 | 0.001** | 0.601 | 0.157 | 0.000*** |
| Expected non-monetary returns | 0.064 | 0.049 | 0.198 | -0.237 | 0.204 | 0.245 | -0.173 | 0.200 | 0.386 | 0.062 | 0.046 | 0.180 | -0.083 | 0.200 | 0.678 | -0.021 | 0.196 | 0.914 |
| Industry sources | 0.050 | 0.037 | 0.176 | 0.127 | 0.203 | 0.532 | 0.178 | 0.202 | 0.379 | 0.050 | 0.035 | 0.155 | 0.074 | 0.189 | 0.696 | 0.123 | 0.188 | 0.511 |
| Industry recipients | 0.031 | 0.049 | 0.530 | 0.393 | 0.233 | 0.091+ | 0.424 | 0.243 | 0.081+ | 0.011 | 0.040 | 0.780 | 0.427 | 0.226 | 0.059+ | 0.438 | 0.233 | 0.061+ |
| Commercialization | | | | | | | | | | | | | | | | | | |
| Development research | 0.008 | 0.033 | 0.809 | 0.720 | 0.171 | 0.000*** | 0.728 | 0.173 | 0.000*** | 0.019 | 0.028 | 0.502 | 0.569 | 0.159 | 0.000*** | 0.88 | 0.161 | 0.000*** |
| Industry funding | 0.011 | 0.032 | 0.725 | -0.014 | 0.184 | 0.940 | -0.003 | 0.184 | 0.988 | -0.007 | 0.028 | 0.805 | 0.027 | 0.166 | 0.871 | 0.020 | 0.168 | 0.905 |
| Industry collaborator | 0.000 | 0.036 | 0.990 | 0.602 | 0.188 | 0.001** | 0.602 | 0.191 | 0.002** | 0.004 | 0.031 | 0.888 | 0.639 | 0.171 | 0.000*** | 0.643 | 0.174 | 0.000*** |
| **Controls** | | | | | | | | | | | | | | | | | | |
| Years worked | -0.003 | 0.002 | 0.168 | | | | -0.003 | 0.002 | 0.168 | -0.003 | 0.002 | 0.189 | | | | -0.003 | 0.002 | 0.125 |
| Organization size (logged value) | 0.021 | 0.014 | 0.127 | | | | 0.021 | 0.014 | 0.127 | 0.016 | 0.012 | 0.174 | | | | 0.019 | 0.012 | 0.110 |
| University collaborators | | | | -0.025 | 0.194 | 0.896 | -0.025 | 0.194 | 0.896 | | | | -0.071 | 0.175 | 0.685 | -0.071 | 0.176 | 0.685 |
| Government collaborators | | | | -0.295 | 0.176 | 0.094+ | -0.295 | 0.176 | 0.094+ | | | | -0.289 | 0.161 | 0.072+ | -0.291 | 0.162 | 0.072+ |
| Microbes | - | | | - | | | | | | - | | | - | | | | | |
| Livestock | -0.023 | 0.038 | 0.545 | 0.346 | 0.262 | 0.186 | 0.323 | 0.260 | 0.213 | -0.025 | 0.034 | 0.475 | 0.263 | 0.247 | 0.287 | 0.238 | 0.244 | 0.330 |
| Aquatics | -0.101 | 0.065 | 0.124 | 0.015 | 0.302 | 0.960 | -0.085 | 0.284 | 0.763 | -0.075 | 0.057 | 0.186 | 0.003 | 0.276 | 0.991 | -0.072 | 0.263 | 0.784 |
| Insects | -0.107 | 0.079 | 0.174 | -0.198 | 0.280 | 0.480 | -0.305 | 0.295 | 0.301 | -0.100 | 0.075 | 0.181 | -0.318 | 0.268 | 0.235 | -0.419 | 0.282 | 0.137 |
| **Model fit indices** | | | | | | | | | | | | | | | | | | |
| Pseudo-$R^2$ | 43.0% | | | | | | | | | 40.4% | | | | | | | | |
| N | 884 (340) | | | | | | | | | 971(366) [a] | | | | | | | | |
| $\chi_M^2$ ($df_M$) | 2.521 (4) , p=0.640 | | | | | | | | | 1.27(4), p=0.866 | | | | | | | | |
| RMSEA (90% CI) | 0.000 (0.000 - 0.041) | | | | | | | | | 0.000 (0.000 - 0.025) | | | | | | | | |
| CFI | 1.000 | | | | | | | | | 1.000 | | | | | | | | |
| $\chi_B^2$ ($df_B$) | 99.58 (37) | | | | | | | | | 103.84 (37) | | | | | | | | |

[a] Item-missings in response on intellectual property (IP) outcomes were not imputed; +p<0.10; *p<0.05; **p<0.01; ***p<0.001

## 5.5. Summary

Findings from probit and structural models provide valuable empirical evidence on the antecedents of exclusive sharing. Table XXVII summarizes the results of hypothesis-testing in both probit and structural models that were run with and without multiple imputations (MI).

Exclusive sharing accompanied by a third-party sharing restriction was largely predicted not by commercialization but by the attributes of the sharing process. Having an industry collaborator on the project does not seem to matter for setting restrictions, nor do industry funding or project innovation activity. While all forms of commercialization were not captured in the analysis, it seems that industry employment of the material-provider only works for setting third-party sharing restrictions.

However, the process through which material providers and receivers share genetic materials appears to be critical for subsequent sharing with a third party. Cross-national sharing embodied substantial obstacles to a third-party transfer. When genetic materials were shared via material transfer agreements (MTAs), they were more likely shared exclusively. Unlike the initial expectation, the reciprocal relationship between material providers and receivers was also found to set a third-party sharing restriction.

Moreover, exclusive sharing was found to be influenced not only by social factors but also by socio-ecological attributes of genetic materials. The significance of ecological conditions from which genetic materials was found to bring about a significant variation in third-party sharing restrictions. Findings suggest that scientists' exclusive sharing cannot be understood without a comprehensive view of socio-ecological system.

TABLE XXVII. HYPOTHESIS-TESTING RESULTS

| | | Probit models | | Structural models | |
|---|---|---|---|---|---|
| | Proposition | w/o MI | w/ MI | w/o MI | w/ MI |
| P1a. | Genetic materials with higher market value will be more likely to be shared exclusively. | Not supported | Not supported | Not supported | Not supported |
| P1b. | Genetic materials with higher non-market value will be more likely to be shared exclusively. | Not supported | Not supported | Not supported | Not supported |
| P2 | Genetic materials of which ecological conditions are significant will be less likely to be shared exclusively. | Not supported | Supported | Supported | Supported |
| P3 | Genetic materials obtained based on a reciprocal relationship will be less likely to be shared exclusively. | Not supported (counter-argument supported) | Not supported (counter-argument supported) | Not supported | Not supported (counter-argument supported) |
| P4 | Genetic materials used in a commercialized research environment will be more likely to be shared exclusively. | Not supported | Not supported | Not supported | Not supported |
| | Hypothesis | | | | |
| H1. | Genetic materials sent to industry researchers will be more likely to be shared exclusively. | Not supported | n.a. | Not supported | Not supported |
| H2. | Genetic materials obtained from industry sources will be more likely to be shared exclusively. | Supported | n.a. | Supported | Supported |
| H3. | Genetic materials obtained from abroad will be more likely to be shared exclusively. | Supported | n.a. | Supported | Supported |
| H4. | Genetic materials that come with a material transfer agreement will be more likely to be shared exclusively. | Supported | n.a. | Supported | Supported |
| H5. | A research project in which genetic materials are exclusively shared without a third party transfer will be less likely to produce journal publications. | Not supported | n.a. | n.a. | n.a. |
| H6. | A research project in which genetic materials are exclusively shared without a third party transfer will be more likely to produce IP-related outcomes. | Supported | n.a. | Supported | Supported |

Predicted sharing restrictions in turn influenced different types of research outcomes to a different degree. A third-party sharing restriction had a positive and significant association with intellectual property (IP) outcomes. Sharing restrictions set at the boundary of the project may provide exclusive benefits to project members and enable them to make use of the material for private gain. In addition, given the structural linkage between exclusive sharing and IP outcomes, broader socio-ecological settings of material-sharing (i.e., cross-national sharing, and formalized sharing with MTAs) appear to directly promote exclusive sharing and indirectly enhance IP production. Nonetheless, the alternative structural models also suggest that the total effects of cross-national sharing on IP outcomes can be weakened, whereas the total effect of MTAs can be strengthened if both direct and indirect effects on IP outcomes are considered.

By contrast, the association between sharing restrictions and publications was not statistically significant. Findings suggest that trade-offs exist in producing research outcomes when a third-party sharing restriction has taken place. Setting a sharing restriction can be beneficial for intellectual property outcomes but does not provide much benefit for publishing articles. The divergent effects of exclusive sharing on different research outcomes may represent two different production systems built in science; in other words, exclusive sharing is a prerequisite for intellectual property outcomes, whereas open sharing and disclosure is required for publications. Nonetheless, the findings also suggest that the linkage between material-sharing and publication outcomes was perhaps weakened. Further investigation is necessary to better understand the way in which exclusive sharing is connected with, and later disconnected from, publication outcomes.

# 6. CONCLUSION

## 6.1. Review

As recognition of the scientific and industrial values of genetic materials has increased (Stern 2004; ten Kate 2002), so have restrictions on access to those materials for research (Campbell et al. 2002; Lei, Juneja, and Wright 2009). Previous literature expresses concerns for the negative consequences that these increasing restrictions place on scientific advance (Eisenberg 2006; Heller and Eisenberg 1998; Lei, Juneja, and Wright 2009). At the same time, counter-measures have begun in order to rebuild the science production system based on open sharing and disclosure, in the forms of several public initiatives (Marshall 1998; McCain 1995; Stern 2004).

Nonetheless, our understanding of access to genetic materials in science is still limited. As a way of assessing access to genetic materials in agricultural research, this study sought to uncover the critical moments when genetic materials begin to be withheld and enclosed by selected entities. Exclusive sharing was defined as the condition in which genetic materials were shared only by selected entities but not transferred to a third-party. From an economic perspective, exclusive sharing represents a transition in the status of goods, from public or common goods available to the public, to private or club goods available only to selected entities. From a managerial perspective, exclusive sharing also embraces mixed components of cooperation and competition in science, in that material-withholding from a third party often occur as a confidential cooperative arrangement with selected partners in a competitive research environment. Acknowledging multi-faceted and context-specific nature of exclusive sharing, this dissertation sought to uncover a specific context in which genetic materials were exclusively shared without a third party transfer.

Theoretical foundations serve to identify the underlying mechanisms generating an uneven distribution of a third-party sharing restrictions. In this study, transaction cost theory, social exchange theory, science institution theory, and socio-ecological system theory were introduced. Transaction cost theory explains exclusive sharing as individual decision-making based on expected benefits and costs (including transaction costs), whereas social exchange theory presents exclusive sharing as a reflection of reciprocal relationships among individuals. Science institution theory directly addresses the issue of exclusive sharing in science. It interprets exclusive sharing as an individual response to an institutional change from open science to proprietary institutions, and conjectures about the potential consequences of exclusive sharing on research outcomes. Socio-ecological system theory illuminates ecological systems in combination with social institutions as a force to shape exclusive sharing patterns. All four of these theoretical perspectives were applied to the hypothesis-development in this study in order to uncover different but complementary social mechanisms that may occur at individual, organizational and societal levels.

Based on theoretical insights, the decision on whether to have a third-party sharing restriction was modeled with socio-ecological antecedents and used to predict the likelihood of producing research outcomes (i.e., publications and IP outcomes). Specifically, agreement on a third-party sharing restriction was predicted by the attributes of four major sharing subcomponents: 1) shared objects (i.e., genetic materials), 2) the sharing actors, 3) the sharing process, and 4) the demand environment in which the actors are situated.

As attributes of shared objects, greater market and non-market values of genetic materials were hypothesized to increase the likelihood of sharing restrictions. The results of this study show that, however, neither market nor information values of genetic materials were significantly associated with a third-party sharing restriction. On the other hand, the significance of ecological conditions from which genetic materials were found creates a significant variation in any third-party sharing restrictions. Findings support a socio-ecological system theory asserting that individuals' sharing patterns cannot be understood without a comprehensive view of a socio-ecological system.

As attributes of the sharing process, this study examined cross-national sharing, formalization with material transfer agreements (MTAs), and reciprocity between material providers and receivers and their associations with a third-party sharing restriction. Results show that the process through which material providers and receivers share genetic materials preconditions subsequent sharing with a third party. Cross-national sharing embodied substantial obstacles to a third-party transfer. When genetic materials were shared via MTAs, they were more likely to be accompanied by a third-party sharing restriction. Unlike the initial expectation on the negative association between reciprocity and a third-party sharing restriction, the positive effects of reciprocity were documented. This unexpected effect of reciprocity challenges the way in which bilateral reciprocity was understood in this study and calls for an alternative explanation of reciprocity and social exchange in general. se they shed light on the sharing process which was not examined by previous studies.

By contrast, this study did not identify a significant effect from commercialization or industry employment, although they were identified a primary cause of exclusive sharing in previous studies. Having an industry collaborator on the project does not seem to matter when setting sharing restrictions, neither do industry funding nor project innovation activity. While all forms of commercialization were not captured in the analysis, it seems that industry employment of the material-provider only works for setting third-party sharing restrictions.

Predicted sharing restrictions, in turn, influenced assorted types of research outcomes to a different degree. A third-party sharing restriction had a positive and significant association with IP outcomes. However, a sharing restriction had a negative and insignificant association with publication outcomes. Findings show that trade-offs exist in producing research outcomes when a third-party sharing restriction has taken place. Setting a sharing restriction can be beneficial for intellectual property outcomes but does not provide much benefit for publishing articles. Nevertheless, the findings also suggest that the linkage between material-sharing and publication outcomes was perhaps weakened. Further investigation is necessary to better understand the context in which exclusive sharing work for or against publication outcomes.

This dissertation revealed the process in which a third-party sharing restriction is set in agricultural research and subsequently influences the publications or intellectual-property outcomes of the project. Understanding of the antecedents as well as the consequences of a third-party sharing restriction would advance our knowledge on exclusive sharing embedded in the modern science production process.

On the one hand, exclusive sharing reflects two divergent production systems connecting material-sharing with research outcomes; in science, exclusive sharing pre-conditions the production of intellectual property outcomes, whereas open sharing and disclosure of some degree may be required for publications. On the other hand, multiple socio-ecological antecedents associated with exclusive sharing represents the complex nature of sharing environments and dynamics which cannot be reduced to pure science production systems. Science production systems are built upon various socio-ecological conditions so that scientists' exclusive sharing cannot be free from socio-economic conditions, national borders and regulations, and the ecological conditions of the genetic materials shared. Furthermore, exclusive sharing comes down to individual and interpersonal decision, so that micro-level interactions among individuals appear to be important to understanding the reason why some researchers gain access to genetic materials whereas others do not.

## 6.2. Contributions and Implications

This dissertation makes multiple contributions to the development of theory and policy. First, theoretical and empirical contributions of this study are articulated with reference to recent studies on material-sharing, science institutions, and research collaboration. Second, it discusses practical and managerial implications for individual scientists and organizational research managers. Lastly, policy implications are specified based on the importance of an access issue in science policy, agricultural policy, and international environmental policy.

### 6.2.1. Theoretical and Empirical Contributions

This dissertation sheds light on exclusive sharing in which genetic materials are shared only by selected entities without being transferred to a third-party. A conceptualization and empirical investigation of exclusive sharing helps us understand the complex nature of bilateral sharing as it differs from open disclosure or general sharing with the public. Attention to exclusive sharing is especially useful for understanding the uneven patterns of material-sharing and research collaboration in a competitive environment.

In an investigation of exclusive sharing, this study links micro-level theories on individual and interpersonal decisions with macro-level theories on institutions and socio-ecological systems. As proposed by an economic theory (Macher and Richman 2008; Williamson 1979), individual scientists continuously seek strategies to increase their own benefits while reducing the costs and risks associated with material-sharing. At the same time, individuals are influenced by relational, institutional, and socio-ecological conditions when deciding whether to share. Acknowledging that both micro-level individual/interpersonal factors and macro-level institutions/systems are critical for scientists' material-sharing, this study develops a comprehensive view of exclusive sharing, not only as a response to institutional changes but also as part of individual and interpersonal decisions. The integration of micro-level and macro-level approaches in this study will facilitate the development of a comprehensive theoretical framework to explaining exclusive sharing and material-sharing in general.

In particular, the conceptual framework developed in this dissertation is differentiated from recent studies on material-sharing (Blumenthal et al. 1997; Campbell et al. 2002; Lei, Juneja, and Wright 2009; Walsh, Cohen, and Cho 2007) in at least two ways.

First, it highlights the importance of the sharing process. The way in which two parties share genetic materials was proposed to directly influence the likelihood of subsequent material-sharing with a third party. The results of this study show that specific features of sharing between material providers and receivers (i.e., formalization through material transfer agreements, and the reciprocal relationship between the two parties) are the most important factors predicting a third-party sharing restriction. This result is in sharp contrast with the insignificant effect of the commercialized research environment. This challenges previous approaches that focus solely on commercialization in science (Blumenthal et al. 1997; Campbell et al. 2002; Lei, Juneja, and Wright 2009) and calls for a more sophisticated model examining specific sharing contexts and processes that directly shape material-sharing patterns among scientists.

Second, this dissertation incorporates global as well as socio-ecological components of material-sharing. Although much of the previous literature does not address the issue of material-sharing at the global scale or material-sharing contingent on specific ecological conditions, this study reveals the significant role of these two components in shaping material-sharing patterns in science. Apparently, scientists' material-sharing is not merely a simple reflection of science production systems but that it is a reflection of the broader socio-ecological systems in which research is conducted. This dissertation uncovers a need to further investigate the broader socio-ecological conditions of material-sharing in order to improve the relevancy of our knowledge on exclusive sharing.

From an analytical point of view, this dissertation is expected to promote empirical research of "action arenas" (Ostrom 1998) in which multi-level motivations of exclusive sharing are integrated and linked with a particular consequence. In particular, an analysis of a specific sharing practice at the project-level presents a way of assessing complex socio-ecological factors shaping a particular sharing pattern and subsequent research outcomes in a certain context. This study can facilitate the development of action-arena-approach and "resource-use-approach" (Padmanabhan and Jungcurt 2012) which focuses on a systematic comparison of specific transactions or events. This study will be particularly valuable for institutional research and socio-ecological system studies to make context-specific cases more comparable and to draw generalizable knowledge from the comparison.

#### 6.2.2. Practical Implications

This study uncovers the specific contexts in which individual scientists engage in material-withholding as well as material-sharing. An examination on this topic advances our understanding of the process by which individuals are included or excluded, delineate boundaries of sharing, and distinguish in-groups from out-groups. The results of this study suggest that when scientists are directly connected to foreign and industry sources, they are more likely to withhold genetic materials and exclude third parties from their boundaries of sharing. Material transfer agreements (MTAs) and bilateral reciprocity are also found to serve only in-groups who shared the materials. These identified conditions can function as multitiered constraints – cross-border constraints, industry control, formal agreements and obligations, and relational constraints – that limit individual scientists' ability to share and produce a certain research outcome. On the other hand, this study also indicates that sharing constraints imposed within a commercialized research environment might not be substantial and the distinction between in-groups and out-groups can become blurred as the significance of complex and uncertain ecological conditions becomes more widely recognized.

For individual scientists who seek access to genetic materials, the identified contexts influencing a third-party sharing restriction can be informative; scientists, as a third party, can gauge the accessibility of genetic materials present in a particular context. When they want to reach genetic materials obtained from abroad or industrial sources, the likelihood of obtaining the material will decrease. On the other hand, scientists may more easily be able to obtain genetic materials for which ecological conditions are considered to be important. The findings also show that scientists, as sharing actors, can be bound by sharing processes; having bilateral agreements or reciprocity can constrain sharing actors from engaging in subsequent sharing with a third party.

Furthermore, practical implications emerge from this study for academic entrepreneurs and research managers who seek to improve research performance. This study uncovers the linkage between exclusive sharing and research outcomes. It can be said that exclusive sharing is a reasonable choice when scientists pursue IP outcomes, because it can directly contribute to the production of IP outcomes. Nonetheless, exclusive sharing may not be a reasonable option when scientists seek to publish journal articles. The identified contrary pattern in which exclusive sharing is connected or disconnected with the two types of research outcomes (i.e., publications versus IP outcomes) suggests that there exist two divergent production systems based on different sharing patterns. Unlike the innovation system theory arguing the convergence of knowledge production and industrial innovations (Etzkowitz and Leydesdorff 2000; Nelson 1993), scientists may not be able to simultaneously achieve two different types of research outcomes especially when they adhere to exclusive sharing practices. Academic entrepreneurs and research managers need to acknowledge that the selection of sharing patterns can lead to a different trajectory of science production. More importantly, it is necessary to devise a material-sharing policy or strategy with consideration for the ultimate outcomes desired.

### 6.2.3. Policy Implications

As introduced in Chapter 2, multiple policies have developed over time to govern the use and exchange of genetic materials at local, national and international levels. These policies are not limited to science or research policies but are applicable to multi-level policies on international trade, agricultural productivity, food security, animal and plant health, public health, and environmental conservation. Despite diverse goals proclaimed by each policy, these policies can be largely categorized into three areas based on the way in which access to genetic materials is understood. One category is comprised of policies advocating exclusive sharing and intellectual property rights. Another category includes policies proclaiming open sharing as a way of advancing public outcomes. A third category designs policies to set national barriers as a way of realizing the proclaimed national outcomes (e.g., the Nagoya Protocol of the Convention on Biological Diversity).

The first two approaches are particularly relevant to science policy. In fact, the exclusive sharing perspective was simultaneously developed with the open sharing perspective in modern science (Barton and Siebeck 1994; David 2004; Rodriguez 2005). On one hand, intellectual property is pursued by a confidential and exclusive arrangement of research and development. On the other hand, publications are promoted by open disclosure and discussion. Nonetheless, there are increasing concerns about the infringement of the open sharing tradition in science given the increasing emphasis on intellectual property and commercialization (Campbell et al. 2002; Lei, Juneja, and Wright 2009). Several policy measures were devised to motivate researchers to share their research materials. These initiatives include mandatory requirements for disclosing research materials upon publication or the receipt of government-funding (Marshall 1998; McCain 1995). They also include more comprehensive approaches to building an open database and bio-banks to collect genetic materials and information in order to help validate previous studies and advance science (Atkinson et al. 2003; Lei, Juneja, and Wright 2009; Volk and

Richards 2008). This dissertation did not directly examine these open-sharing policies and initiatives, but indirectly capture the presence of these movements; the results of this study suggest that exclusive sharing may be negatively associated with publications. However, the association between sharing patterns and publication outcomes was not statistically significant. No structural linkage between the sharing process and the publication production process was found, which may suggest that sharing practices are decoupled from publication activities. Based on these findings, several recommendations can be made to assist open-sharing policies.

First, for the success of open-sharing initiatives, the positive linkage between open sharing and publications needs to be acknowledged and realized at the individual level. Even though the benefits from open sharing are obvious at the field level, individuals are more likely to engage in material-sharing when they foresee a direct benefit of sharing on their publications. Straightforward policies mandating open disclosure of research materials for publications would be one way to promote open sharing of genetic materials in science. However, there is always a possibility for individuals to bypass the mandates in a pre-publication stage and to devise a hybrid strategy to pursue publications without losing control over genetic materials. Therefore, it is important to devise formal and informal incentives that will motivate individuals to engage in open sharing.

Second, any open sharing policy in science needs to incorporate broader understanding of the socio-ecological system that shape scientists' access to genetic materials. Although much discussion has been devoted to how to mitigate the negative consequences of intellectual property rights protections or proprietary institutions in science (Lei, Juneja, and Wright 2009), this study shows that scientists' access to genetic materials is closely linked to the broader socio-ecological context beyond the science production system. Open sharing policies need to be diversified depending on the significance of the ecological conditions in which genetic materials are found. As suggested by socio-ecological system theory, it might not be possible to establish a one-size-fits-all standard policy applicable to various types and kinds of genetic materials given the divergent socio-ecological trajectory in which the materials have been sustained, used and exchanged.

Public initiatives to build bio-banks or gene banks need to consider how to overcome the substantial national barriers identified in this study when collecting and redistributing genetic materials from abroad. The initiatives should also reconsider the effectiveness of material transfer agreements (MTAs) as a tool of mandating open sharing. As shown in this study, MTAs are more likely to be used to set a third-party sharing restriction. Despite public initiatives to promote open sharing via MTAs, procedural barriers and administrative burdens may discourage scientists from using MTAs, especially when genetic materials are freely available. Formalized procedures may not be applicable to highly informal material-sharing practices of scientists. A policy mandating the use of MTAs without an in-depth understanding of the way in which MTAs are perceived and adopted by individual scientists can reinforce the current tendency to use MTAs for setting sharing restrictions rather than mandating open sharing.

Similar recommendations can be made for the current international policy that attempts to build a global-wide gene bank. The International Treaty on Plant Genetic Resources for Food and Agriculture (IT PGRFA) typically aims to create a global community that shares plant genetic resources without any additional requirements (Halewood and Nnadozie 2008; Santilli 2012, 118). This grand plan can be realized only when individual member countries and organizations foresee a direct linkage between material-sharing and any outcomes of interest and accordingly donate genetic materials of value to the global system. IT PGRFA also needs to acknowledge the substantial barriers to cross-national sharing and constraints accompanied by material transfer agreements.

Lastly, this study provides a timely insight into the recent development of the Nagoya Protocol in the Convention on Biological Diversity (CBD). The CBD has promoted a policy encouraging sovereign rights over biological resources (Koopman 2005; Merson 2000; Santilli 2012). In line with this policy, the Nagoya Protocol (NP) was adopted in 2010 by CBD member countries. The protocol further specifies conditions for access and benefit-sharing (ABS) through which resource-users gain access to genetic materials with informed consent from material-providers and have an obligation to provide monetary and non-monetary compensation back to material providers.

Nonetheless, findings of this study reveal two important phenomena relevant to the implementation of the NP. First, despite the existing concerns about bio-piracy, this study shows that genetic materials from abroad often carry sharing restrictions. Although this is a partial observation of US agricultural research activities in 2010 and 2011 when the NP was not fully implemented, the finding suggests that there already exist substantial cross-national sharing barriers. New formal procedures and requirements specified by the NP can increase existing cross-national sharing barriers, so they need to be applied in a flexible way. Adding one more layer of procedures without considering pre-existing cross-national barriers can dampen material-sharing across nations and stifle global scale research and development. Second, the findings of this study also show that a substantial proportion of projects had an expectation to return non-monetary benefits to material-providers, even when the NP has been fully institutionalized. This may indicate that researchers and material-users might have already developed their own way of reciprocating benefits acquired from the use of genetic materials among themselves (Welch, Shin, and Long 2013). Although further investigation on use and exchange of genetic materials, particularly wild life obtained from nature, needs to done before making any concluding remark, the observations from a part of the US agricultural researchers suggest that the NP could add complexity to scientists' current material-sharing practices and might counteract them. Careful assessment of the direct effects of the NP on scientists' material-sharing and subsequent research productivity is required to better implement the NP while mitigating its negative consequences.

## 6.3. Limitations and Future Research

### 6.3.1. Limitations

This dissertation develops an unusual framework incorporating micro-level individual/inter-personal approaches with macro-level institutional/system-based approaches to explain variances in exclusive sharing in agricultural research. Uncovered antecedents and consequences of exclusive sharing help to advance understanding of the socio-ecological contexts as well as the divergent science production modes associated with exclusive sharing. Even so, there are several noteworthy limitations of this research.

First, it needs to take a caution when one generalizes the findings of this study to a population of U.S. agricultural researchers using one of the eight kinds of non-plant genetic materials, given the lack of knowledge on the target population. Although the snowball sampling process incorporated in both the 2011 and 2012 surveys shows that a large proportion of researchers nominated by survey respondents during the survey were found to have already been invited to participate, this cannot be directly interpreted as the coverage of the study sample. Since the target population is a very specific researcher group, caution should be exercised in making a general statement about the target population based on the findings of this study. Moreover, this dissertation used project-level data reported by those who used genetic materials and currently had research projects on the materials. This subset of the sample was more likely to have research-oriented activities when compared to the rest of the respondents. Therefore, readers need to acknowledge the additional bias associated with the selection of the subsample.

Second, the results of this research do not imply causal relationships. Since this dissertation used cross-sectional data for which variables of interest were measured at one-point in time, the causal relationship proposed in the theoretical model could only be treated in a limited way. Antecedents and consequences of exclusive sharing are conjectured from the events and components observed in a timely order. The findings can only identify significant associations between key variables. The proposed sequential process through which a scientist shares genetic materials exclusively and then produces a certain type of research outcome cannot be confirmed without longitudinal and experimental research identifying the independent causal effects.

Third, this research relies on survey data that are not specifically designed for the theoretical model developed in this study. As a result, some measures are neither precise nor comprehensive enough to capture the proposed concepts and constructs in full. Most of concepts, except those in commercialized environments, were measured with a single indicator. For example, exclusive sharing was only captured by one variable indicating material receivers' agreement on a third party sharing restriction. However, it is still possible that a third-party sharing restriction occurred without their agreement. Exclusive sharing can also occur without a third-party sharing restriction. A limited measure might have underrepresented the presence of exclusive sharing in agricultural research. Market and non-market values of genetic materials were also measured in a limited manner. Commercialized settings capture research environments in which genetic materials were used instead of the general research fields in which potential sharing actors, such as material providers, receivers and third parties, were situated. Moreover, measures of some constructs included in the theoretical model (e.g., scientific competition of a research environment, and individual research capacities of all project members) were not present in the survey data, so they were not able to be incorporated in an empirical analysis. Inherent limitations in measurement need to be acknowledged in interpreting the results of this dissertation and drawing implications from them.

Lastly, this dissertation aims to investigate the consequences of exclusive sharing on research outcomes achieved by project members within a relatively short time period (i.e., outcomes produced during the recent two years). Some of these projects may have just started at the time of the survey, so it is possible that the publication outcome measured in this study underestimates the production of publications and IP outcomes that are not realized in a short time period. Moreover, the effects of sharing restrictions on research outcomes were examined within the team at only one point in time. Therefore, the findings cannot be generalized to a macro-level conclusion on the effects of exclusive sharing on research outcomes that accrue over time in the field or at a societal level outside the project team. Furthermore, this dissertation only takes into account the association between exclusive sharing and research outcomes without questioning any consequences for other ecological and societal outcomes, such as ecological sustainability and societal equity. Hence, extra caution needs to be applied when interpreting the implications of exclusive sharing on potential societal benefits.

### 6.3.2. Future Research Agendas

Theoretical and methodological gaps identified in this dissertation generate multiple future research agendas. For theory-development, additional intellectual endeavors are required to explain how and why specific sharing contexts between two parties directly influence material-sharing with a third-party. Although transaction cost theory and social exchange theory provide a partial view on why certain sharing attributes between two parties generate variations in a third-party sharing restriction, several critical questions remain unanswered. What is a primary driving force creating a third-party sharing restrictions in cross-national sharing? Are the restrictions mostly requested by material providers abroad, or are they more likely set by material receivers in the US? How have material transfer agreements (MTAs) been used for setting sharing restrictions instead of requesting open-sharing? Are there any gaps between institutional designs for MTAs and individuals' actual use of MTAs? If so, what factors account for the gaps? Theoretical rationales need to be developed in order to explain the underlying causes and motivations of observed phenomena, that is, the close association between the sharing process and exclusive sharing.

In particular, the unexpected effect of bilateral reciprocity on exclusive sharing calls for an in-depth understanding of the way in which multi-faceted reciprocity (i.e., bilateral reciprocity, indirect reciprocity, and general reciprocity) influence different types of material-sharing (i.e., bilateral sharing, sharing with a third-party, and open sharing with the public). As argued by Shibayama et al. (2012), bilateral reciprocity between two parties may work only for bilateral sharing between the two, without evolving into subsequent sharing with a third party or sharing with the general public. A reliance on bilateral reciprocity may crowd out altruistic attitudes to make a generous offer to a third party. Nonetheless, the identified positive association between bilateral reciprocation and exclusive sharing does not necessarily negate insights drawn from studies on indirect reciprocity and third-party altruism (Berger 2011; Boyd and Richerson 1989; Nowak and Sigmund 2005). Further examination is warranted regarding the extent to which bilateral reciprocity between two parties coincides or conflicts with reciprocity toward a third party or the general public. Future research is also needed regarding the way in which bilateral reciprocity among individuals coevolves into general reciprocity at the societal level and how, in turn, this affects individuals' decision to engage in either material-sharing or material-withholding.

The conceptual model can be further advanced in future research by incorporating additional key factors of exclusive sharing. The locus of control over genetic materials and power dynamics among sharing actors can create additional variations in exclusive sharing. Which party wants to hold, and which actually holds control over the flow of genetic materials? Who has primary decision authority on exclusive sharing? Although this dissertation does not directly examine the role of power dynamics among sharing actors, part of the findings provide a glimpse of the power issues in exclusive sharing. For example, industry entities appear to exert power for setting a sharing restriction when they give their own materials to others, but not when they obtain genetic materials from others. Larger organizations seem to create more constraints limiting individuals' open sharing, whereas individuals tend to be less bound by sharing restrictions as their professional experiences accrue. Further investigation into the locus of control over genetic materials and power dynamics among sharing actors can advance our understanding of exclusive sharing.

In addition, empirical analyses can be furthered with alternative measures, advanced modeling, and observations from various populations. First, the direct and indirect effects of socio-ecological factors on research outcomes can be further assessed, although this study only captures indirect effects via exclusive sharing on research outcomes. The understanding of the direct as well as the indirect effects of socio-ecological attributes of genetic materials can facilitate discussion on the role of socio-ecological sharing conditions in science production. Second, the effects of the commercialized and competitive research environment on exclusive sharing can be further investigated. In this study, commercialized environments were limitedly investigated whereas competitive environments were not reflected into the analytical model. Hence, it is still possible that these environments directly and indirectly influence sharing patterns. For instance, commercialized environments can change the perceived market and non-market values of genetic materials, use patterns of material transfer agreements, and any perceptions of expected bilateral reciprocation and indirectly influence material-sharing practices. Further investigation is necessary before confirming that research environments are not associated with exclusive sharing. Lastly, the association between two different research outcomes can be further examined given the rise of patent-paper pairs. Additional investigation of the linkage between publications and IP outcomes may help develop a new model of exclusive sharing in which material-sharing, publications and IP outcomes are connected with one another.

Last but not least, this paper identifies tensions and trade-offs in the process through which exclusive sharing promotes, as well as hinders, different types of research outcomes. Nonetheless, research outcomes would be just one kind of societal outcomes achieved from genetic materials. Given the multiple functions of agriculture and agricultural research in a society (Santilli 2012), it needs to be further understood how and to what extent exclusive sharing influences societal outcomes, such as agro-biodiversity, food safety, animal and plant health, public health, as well as agricultural productivity. Long-term gains and losses associated with scientists' material-sharing need to be better understood. It would be also worthwhile to assess how and to what extent exclusive sharing are associated with broader societal benefits and costs relevant to diverse stakeholders, gene bank managers, farmers, breeders and others who have keen interests in genetic materials.

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# APPENDIX A.

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

**Exemption Granted**
**UIC Amendment #3**

September 16, 2011

Eric Welch, PhD
Public Administration
412. S Peoria Street, CUPPA
Suite 138, M/C 278
Chicago, IL 60612
Phone: (312) 413-2416 / Fax: (312) 996-8804

**RE: Research Protocol # 2010-0086**
**"Knowledge for Policy: Critical Research for Understanding Potential Impacts of ABS on Eight Sectors of Genetic Resources for Food and Agriculture"**

Sponsor: US Department of Agriculture
PAF#: **2010-00315**
Grant/Contract No: **2009-05478**
**Grant/Contract Title:** Knowledge for Policy: Critical Research for Understanding Potential Impacts of ABS on Eight Sectors of Genetic Resources for Food and Agriculture

**Dear Dr. Welch:**

Your amended Claim of Exemption was reviewed on September 16, 2011 and it was determined that your research meets the criteria for exemption. You may now implement the amendment to your research.

**Amendment Summary:** UIC Amendment #3 initially submitted on April 11, 2011 is an investigator-initiated amendment:

1) Change in principal investigator from Jennifer Long to Eric Welch;

## APPENDIX A (Continued)

2) Adding a new data source: Two publicly available data sets for the exchange of micro-organisms from the USDA Peoria Culture Collection in Illinois. The data does not include any direct or indirect identifiers. Only organization names and organization addresses are included in the file. Prior to analysis, organization name and address will be removed to increase confidentiality.

**Exemption Period:** **September 16, 2011 – September 15, 2014**

Amendment Approval Date: September 16, 2011

The specific exemption category under 45 CFR 46.101(b) is:

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

Information for Human Subjects UIC Policy requires investigators to provide information about the research protocol to subjects and to obtain their permission prior to their participating in the research. The information about the research protocol should be presented to subjects in writing or orally from a written script. When appropriate, the following information must be provided to all research subjects participating in exempt studies:

a. The researchers affiliation; UIC, JBVMAC or other institutions,
b. The purpose of the research,

**APPENDIX A (Continued)**

c. The extent of the subject's involvement and an explanation of the procedures to be followed,
d. Whether the information being collected will be used for any purposes other than the proposed research,
e. A description of the procedures to protect the privacy of subjects and the confidentiality of the research information and data,
f. Description of any reasonable foreseeable risks,
g. Description of anticipated benefit,
h. A statement that participation is voluntary and subjects can refuse to participate or can stop at any time,
i. A statement that the researcher is available to answer any questions that the subject may have and which includes the name and phone number of the investigator(s).
j. A statement that the UIC IRB/OPRS or JBVMAC Patient Advocate Office is available if there are questions about subject's rights, which includes the appropriate phone numbers.

Please be sure to:

→ Use your research protocol number (2010-0086) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 355-2908. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne, B.S.
Assistant Director, IRB # 2
Office for the Protection of Research Subjects

cc: James R.. Thompson, Public Administration, M/C 278

## APPENDIX B.

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

**Exemption Determination**
**Amendment to Research Protocol – Exempt Review**
**UIC Amendment # 1**

July 19, 2010

Jennifer Long, Ph.D.
Public Administration
138 CUPPA Hall
412 S Peoria Street, M/C 278
Chicago, IL 60607
Phone: (773) 384-2053 / Fax: (312) 996-8804

**RE: Protocol # 2010-0086**
**"Knowledge for Policy: Critical Research for Understanding Potential Impacts of ABS on Eight Sectors of Genetic Resources for Food and Agriculture"**

Dear Dr. Long:

The OPRS staff/members of Institutional Review Board (IRB) #2 have reviewed this amendment to your research, and have determined that your research protocol continues to meet the criteria for exemption as defined in the U. S. Department of Health and Human Services Regulations for the Protection of Human Subjects [(45 CFR 46.101(b)].

The specific exemption category under 45 CFR 46.101(b) is:

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

## APPENDIX B (continued)

You may now implement the amendment in your research.

Please note the following information about your approved amendment:

**Exemption Period:** **July 19, 2010 – July 18, 2013**

**Amendment Approval Date:** July 19, 2010

**Amendment:**

Summary: UIC Amendment #1 dated July 1, 2010 and submitted to OPRS on July 12, 2010 is an investigator-initiated amendment. The amendment involves an additional phase of the project to conduct an on-line survey to collect quantitative data on the use and exchange of biological materials from a large number of individuals working in food and agriculture in the US. The sample frame comprises government, private sector, and university users and researchers in eight sectors of genetic resources for food and agriculture. The overall sample size will be approximately 4000 researchers in eight specific sectors of genetic resources. Considering the typical response rate of less than 50%, approximately 2000 responses are expected. The amendment includes the following:

1) Revised Research Protocol (Version 2, dated July 1, 2010);
2) Revised (LONG) Informed Consent, Survey Webpage Entry, July 01, 2010, v3;
3) Revised Recruiting Letter; July 1, 2010; V3;
4) New Email Reminder; July 1, 2010; V1; and
5) New (LONG) Online Survey Instrument; July 1, 2010; V1

**You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:**

Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

## APPENDIX B (continued)

<u>Information for Human Subjects</u> UIC Policy requires investigators to provide information about the research protocol to subjects and to obtain their permission prior to their participating in the research. The information about the research protocol should be presented to subjects in writing or orally from a written script. <u>When appropriate</u>, the following information must be provided to all research subjects participating in exempt studies:

a. The researchers affiliation; UIC, JB VAMC or other institutions,
b. The purpose of the research,
c. The extent of the subject's involvement and an explanation of the procedures to be followed,
d. Whether the information being collected will be used for any purposes other than the proposed research,
e. A description of the procedures to protect the privacy of subjects and the confidentiality of the research information and data,
f. Description of any reasonable foreseeable risks,
g. Description of anticipated benefit,
h. A statement that participation is voluntary and subjects can refuse to participate or can stop at any time,
i. A statement that the researcher is available to answer any questions that the subject may have and which includes the name and phone number of the investigator(s).
j. A statement that the UIC IRB/OPRS or JB VAMC Patient Advocate Office is available if there are questions about subject's rights, which includes the appropriate phone numbers.

Please be sure to:

→Use your research protocol number (2010-0086) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact me at (312) 355-2908 or the OPRS office at (312) 996-1711. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne, CIP
Assistant Director, IRB # 2
Office for the Protection of Research Subjects

Enclosure(s): None
cc: James R. Thompson, Public Administration, M/C 278

# VITA

NAME: Eunjung Shin

EDUCATION:

B.E., Kyungpook National University, 2000.
M.C.P., Environmental Planning, Seoul National University, 2003.
PhD., Public Administration, University of Illinois at Chicago, 2013.

PROFESSIONAL EXPERIENCES

Lecturer, Public Administration Undergraduate Program: Environmental Policy, University of Illinois at Chicago, 2013.

Research Associate, Science, Technology, and Environment Policy Lab, Public Administration, University of Illinois at Chicago, 2009-2013.

AWARDS

The Distinguished Graduate Scholar Fellowship (a stipend and a tuition waiver), The College of Urban Planning and Public Affairs, University of Illinois at Chicago, U.S., 2009-2013.

The Pre-doctoral Fellowship Competition ($10,000), The Institute for Environmental Science and Policy, University of Illinois at Chicago, U.S., 2012-2013.

PUBLICATIONS

Welch, E. W., Shin, E. & Long, J. V. (2013). Potential Effects of the Nagoya Protocol on the Exchange of Non-plant Genetic Resources for Scientific Research: Actors, Paths, & Consequences, *Ecological Economics*, 86, 136-147.

Shim, J., Shin, E. & Johnson, T.P. (2013). Self-Rated Health Assessed by Web vs. Mail Modes in a Mixed Mode Survey: the Digital Divide Effect and the Genuine Survey Mode Effect. *Medical Care*, 51(9), 774-781.

Shin, E. & Welch, E.W. (2012). Environmental Auditing and Compliance, *Handbook of Sustainable Management* (pp. 353-378), C. N. Madu and C. H. Kuei (eds.), World Scientific Publishing.

Shin, E. (2012). Attitudinal Determinants of E-Government Technology Use Among U.S. Local Public Managers. *Proceedings of the 45th Hawaii International Conference on System Sciences (HICSS),* 2613-2622.

Shin, E., Johnson, T. P., & Rao, K. (2012). Survey Mode Effects on Data Quality: Comparison of Web and Mail Modes in a U.S. National Panel Survey, *Social Science Computer Review*, 30 (2), 212-228.