The Economic Organization of Biomedical Research in the U.S.

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Abstract

This paper analyzes the economic organization of biological materials and research in the United States, focusing particularly on human biological materials and biomedical research. The economic nature and the property rights arrangements that govern biological materials and biomedical research are quite complex, which has important implications for developing comprehensive research collections and exchanges. There is no single market for exchange nor is there a discernable "commons": biomedical exchange involves a number of different types of transactions and many centers of decision making. Theories of efficient governance predict that biomedical exchange is best organized using polycentric principles and diverse contracting mechanisms, property rights, and regulatory schemes. Contracting mechanisms include market, trilateral, and relational contracting principles. Intellectual property rights arrangements include unrestricted access and use, confidentiality and proprietary information agreements, licenses, and patents. Regulatory solutions include limited regulation, self-regulation, and third party-ordering. The organization of biomedical research in the U.S. provides an excellent opportunity for further research on efficient governance.

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Introduction

We have collected and studied biological materials for centuries in order to improve our lives. An extraordinarily diverse assortment of biological materials have played a major role in advances in treating diseases that affect both public and private health including polio, tuberculosis, malaria, HIV/AIDS, cancer, heart disease, diabetes, and stroke. In addition, analyses of biological materials have played a major role in advances in agricultural productivity, animal health, and materials science.

In order to make and apply discoveries in biology, researchers must have access to comprehensive sources of high quality biological materials and the results of biological research. However, research and development is inherently risky and competitive: sunk costs are high and most research does not produce a return on costs; funds are scarce and alternative uses such as clinical treatment, teaching, or physical plant are often more compelling in the short term; considerable effort is required to make scientific discoveries and apply them to address public health issues, yet it is quite difficult to adequately reward this effort; working with biomaterials, exchanging them, and disclosing research results may expose humans to hazards such as violations of privacy, ethical concerns, or potentially fatal infectious diseases. Hence there is an inherent tension between sharing

materials and research on an open, non-proprietary basis with maintaining the types of incentives required to invest in doing safe, high quality research on a sustained basis.

Unsolved questions about organisms, recent advances in sequencing the human genome and other developments in biology and analytical technologies, bioterrorism, and global health pandemics create new pressure to collect, produce, analyze, store, and exchange biological materials and research, and to do so as efficiently as we can. Analysts who are interested in these issues have proposed a number of institutional frameworks and governance solutions ranging from market exchange under private control and hierarchical arrangements under public control. Some draw an analogy to common pool resource management, suggesting that institutions that have been effective in governing natural resources may be effective in governing biomaterials and research products. Yet the economic organization of biomedical collection and research are under-researched and without a clear theoretical and empirical understanding, solutions are at best premature. In the worse case, ill-specified solutions have a high potential for failure, which could have profound consequences for human survival.

Polski (2005) analyzes the institutional economics of non-human biological materials and biomedical research and concludes that: 1) they have a mixed economic nature that evolves over time; and 2) they are most efficiently governed by relational contracting. In this paper, I extend the analysis to develop a better understanding of the institutional economics of human biological materials and biomedical research. The questions associated with this analysis include:

(1) What is the nature of biological materials? Why are they collected, how are they used, and how are they transmitted, transformed, and stored?

(2) What is the value of different types of biological materials and to whom does this value accrue? How do these values change over time?

(3) What are the institutional economics of biological materials and biomedical research?

(4) What are the principles upon which we can more effectively share biological materials and the results of biomedical research?

Section One analyzes the collection and uses of biological materials and places them in an economic and institutional context. Section Two provides an overview of the economic nature of biological materials and research. Section Three analyzes exchange of human biological materials and research in the U.S. Section Four analyzes the implications for governance, and Section Five summarizes and concludes.

1: Collecting and Using Biological Materials

Collection

Biomedical research requires samples of human biological materials (HBMs), non-human biological materials (NHBMs), and engineered biological materials (EBMs). HBMs such as blood, DNA, organs, and tissues, are collected from individuals through routine

diagnostic examinations, surgical procedures, direct donation, autopsy, identification or forensic analysis, and exchange.

HBMs are collected and stored by a wide range of individuals and organizations including government agencies, medical practitioners, researchers, laboratories, hospitals, educational institutions, and commercial services. However, there is no comprehensive database that reliably captures information about stored HBMs worldwide, nor is there a comprehensive framework for regulating them.

NHBMs such as samples of flora and fauna that may help us understand biological processes or have beneficial properties, as well as microbial material such as bacteria and viruses are collected from natural resources, animals, and humans. Samples of microbial material are often collected in the same way as HBMs. However, they may also be collected by bioprospecting in natural resources, particularly tropical forests in the "mega diverse countries" of Australia, Brazil, China, Colombia, Ecuador, India, Indonesia, Madagascar, Malaysia, Mexico, Peru, and Zaire.[1]

As is the case with HBMs, there is no comprehensive database that reliably captures information about stored NHBMs: existing databases are developed and maintained by an equally rich assortment of individuals and organizations. However, there is a

[1] For an analysis of bioprospecting, see Polski, (2005).

comprehensive set of international rules, the Convention on Biological Diversity, which provides a framework for regulating the use of NHBMS.[2]

Biological materials are not always collected from natural sources: they can also be engineered in the laboratory (EBMs). Once a natural biological material has been identified and described, often it can be replicated. Moreover, tissue engineering technologies provide biomechanical alternatives for tissues or combine bioengineered substances and materials with HBMs. As is the case with HBMs, there is no comprehensive database of information about EBMs nor is there an established international regulatory framework.

Uses

While HBMs, NHBMs, and EBMs differ in some very important ways, some aspects of collection and use are quite similar. There are five general types of individuals and entities that collect biological materials: Practitioners; Educators; Basic Researchers; Applied Researchers; Commercial Services. Each type of collector has distinct but often overlapping purposes, which are summarized in Table 1.

Practitioners, such as physicians and veterinarians, collect, analyze, and store specimens in order to diagnose or treat medical problems. In the process, they may advance knowledge or develop new therapies but their main economic interest is to protect and care for their patient. Once they have analyzed a specimen to obtain the information needed to successfully treat their patient, they have no further need for the material.

[2] For information on the Convention, see www.biodiv.org. For a discussion of the relevance for understanding the institutional economics of biological materials, see Polski, 2005.

Educators collect, analyze, and store specimens to train others to practice and to do biomedical research. Educators archive and store specimens for educational purposes: when they are no longer useful for this purpose, they have no further need for the material.

Basic Researchers collect, analyze, and store biological materials to conduct research that will advance knowledge, which may help a Practitioner, Educator, or Applied Researcher understand problems, solve problems, or develop new therapies. Basic Researchers archive and store specimens for their research: when they are no longer useful for this purpose, they have no further need for the material.

Applied Researchers collect, analyze, and store specimens to develop new therapies that solve problems, which may be developed on a proprietary or non-proprietary basis. In the process they often advance knowledge. In the course of their research, they archive and store specimens, however, once research and testing is complete, they have no further use for the materials.

Commercial Services may collect biological materials to provide analytical services, for proprietary use, or for storage and distribution purposes. For example, diagnostics and forensics laboratories provide testing and identification services; other commercial services provide tools to facilitate analysis or for quality control in diagnostic and pathologic laboratories, engineer cells and tissues for research, or provide other custom

services using proprietary tissues. Service enterprises such as organ and blood banks archive and store materials for future use or for exchange.

While all those who use biological materials would benefit from access to comprehensive collections and a standard set of rules that regulate collection and use, they do not necessarily have incentives to contribute to the cost of building and maintaining useful archives, repositories, and exchange systems because their economic motivations and use of biological materials differs.

For example, Educators, Basic Researchers, and Applied Researchers all have an interest in advancing knowledge. Practitioners and Commercial Services may share this interest but they are less directly involved in knowledge production: their concern is providing medical services to meet demand. Similarly, Practitioners and Applied Researchers have a common interest in problem solving that is not directly shared by Educators, Basic Researchers, or Commercial Services. Applied Researchers and Commercial Services each have an interest in creating new and profitable products, processes, and applications that is not completely shared by other users. Finally, of all users, it is Commercial Services that are most likely to be engaged in exchanging materials, and hence interested in activities that augment the value of the materials that they collect.

Centuries of collection experience demonstrates that common interests are not sufficient to overcome the collective action problems associated with developing and sustaining comprehensive collections or exchanges of biological materials. This failure is due, in

part, to the structure of the market for exchange: producers are distinct from collectors; collectors may or may not be distinct from users; collectors and users may become producers; any of these participants may be but not all are traders. Moreover, many of the participants in this exchange situation are not sensitive to price or profitability. In other words, there is no common market: instead there are a number of distinct types of transactions that create the need for specialized markets. The nature of these markets and the potential for achieving efficiencies is further developed in the sections that follow.

2: The Economic Nature of Biological Materials and Research

We have two perspectives on the economic nature of a good or service. The first is a static perspective, which focuses on the inputs and outputs to economic transformation processes. The second perspective is dynamic: it focuses on the economic transformation process itself. Both perspectives are important for understanding the economic nature of biological materials and research.

Static Aspects

Standard economic theory posits four classes of goods and services: 1) private; 2) public; 3) club or toll; 4) common pool. The differences among these types of goods have important implications for estimating and allocating the value of producing and providing them, and for efficiently organizing and governing supply and demand.

The economic nature of a good or service can be determined by two attributes 1) the extent to which consumption reduces the supply available to others (subtractability), and 2) the extent to which access to the good or service can be controlled (excludability). Arraying these attributes in a two-by-two matrix with a high/low scale gives us a taxonomy of goods and services that includes private goods, which have high subtractability and high excludability; public goods, which have low subtractability and low excludability; club or toll goods, which have low subtractability but high excludability; and common pool goods, which have high subtractability and low excludability.

Theoretically, the economic nature of a good or service prescribes the way in which it is most efficiently owned and governed, which is summarized in Figure 1.[3] Private goods are best owned by private individuals or entities, and either self or market-governed; common pool and club goods are best owned and governed collectively by those who benefit from access; and public goods are best owned and governed by polities.

On a static basis, biological materials and research are inputs or outputs of human resources, natural resources, or human enterprise. HBMs are components of genetically unique human beings, who, in a strictly economic sense, are private goods: when an individual is removed from the species it subtracts from the supply of human diversity, and one can control access to an individual and his or her biological material at relatively low cost.

[3] For an analysis of the institutional implications of this taxonomy, see Appendix in Polski (2005).

EBMs and research products are the outcomes of human enterprise, which, in the absence of rules to the contrary, produces private goods. That is, the fruits of human labor are private goods until or unless the producer, who produces and controls a specific supply of products or services, yields property rights to others or makes other governing arrangements.

By contrast, NHBMs are components of natural resource systems. Natural resources are common pool goods: one user's consumption of the components of a natural resource subtracts from the supply available for others yet the physical nature of the resource makes it very costly to control access to the resource and its biological materials.

Biological materials and research products such as publications and inventions may be inputs to or outputs of economic transformation processes that produce other types of goods and services, e.g. education, medical therapies, agricultural production, or commercial trade. However, until biological materials and research products are integrated into new value chains and transformed from one type of good to another, we can think of them as assets with a mixed investment character that are either private or common pool goods. Figure 2 summarizes the static economic nature of biological materials and research products.

Dynamic Aspects

The process of creating a collection of biological materials, engineering biological materials, or doing research cannot be analyzed from a static perspective: these activities are creative, risky, inter-temporal asset transformation processes that have the potential to produce both tangible and intangible goods and services with distinct economic values. Similarly, problem solving, new product development, and exchange are also risk and time-sensitive asset transformation processes.

To completely understand the institutional economics of an asset transformation process, one must analyze the process in some detail, considering who participates, the roles they play, the nature of their information, the level of control they have over actions and outcomes, the actions they can take, possible outcomes, how actions are linked to outcomes, costs, and benefits, and the context within which the process takes place.[4] This paper uses biomedical research in the U.S. as an example to empirically ground this analysis.

Political and economic activity in the U.S. is private-sector led and export-oriented. Biomedical research is conducted by academic researchers, medical professionals, researchers in non-educational research institutes and governments, and commercial researchers. Biomedical research and materials exchange is regulated and highly competitive, which has important implications for market exchange.

[4] Note the similarity to a game-theoretic analysis. For an institutional approach to policy analysis and design, see Polski and Ostrom (1999). For analyses of the research process and some of the institutional economics issues associated with research and development, see Polski (2005; 2000).

In the first phase of research, a researcher collects and integrates information and materials from a variety of sources to formulate an idea about how things work, e.g. private knowledge; research findings in public and private domains; analyses of biological materials. The researcher engages in a creative enterprise, in which s/he transforms a bundle of tangible and intangible goods into new knowledge. This knowledge is an intangible asset that may have a number of potential applications or just one potential application. Until s/he shares this knowledge with others, it is a private good.

However, biomedical researchers in the U.S. rarely work alone. In most cases, they work in a research group, in which case knowledge and materials may be jointly formulated or shared within the group. In the second phase of research, tangible assets such as biological materials, databases, and equipment, and intangible assets such as theoretical formulations and experimental results are created and shared within the research group. These shared assets take on the characteristics of club or toll goods: that is, the supply of the assets can be "consumed" by members of the group without subtracting from the supply available to the group, and access to the assets can be restricted at relatively low cost.

In the third phase of research, assets are potentially transformed into research products that have economic value. Research products may have commercial, non-commercial, or mixed values. Typical research products include databases, collections of biological

materials, publications, inventions that can be patented or licensed, and specialized know-how.

With the exception of specialized know-how, which is embodied in individual capacity and is a private good, the other goods that a research group controls are club goods that the researchers may further transform into public goods or private goods. For example, a research group may choose to control their rights over their research products by keeping their results secret; forego their rights by placing their research products in the public domain; or transfer their rights to an individual or some form of unified collective entity such as a firm, university, or government agency. When a research group in the U.S. produces a patentable or licensable invention, they may "privatize" the right to appropriate economic benefits from developing this product, but the knowledge itself enters the public domain.

The objective of basic research is to produce knowledge products for a small group of highly specialized consumers: theoretical models and empirical findings that advance knowledge in a discipline for other researchers in the same discipline with similar research interests. In the U.S., basic research products are considered a quasi-public good and they are not expected to earn a return on investment: the cost of production is subsidized by public and philanthropic organizations with an interest in advancing knowledge. On the other hand, the objective of applied research in the U.S. is to produce specific products or inventions such as drugs or medical devices that solve a health problem and can earn a return on investment in research, production, marketing, and

distribution. The cost of applied research is born by a combination of private, public, and philanthropic sources. Figure 3 depicts the economic nature of a basic research process and Figure 4 depicts the economic nature of an applied research process that produces a specific asset.

While both basic and applied researchers may develop collections of biological materials and databases of information, producing these by-products is not their main objective or area of expertise nor do their reputations or economic returns depend upon their success in developing collections for wider use. Moreover, the cultural norms of basic and applied researchers with respect to sharing research materials are quite different. Basic researchers are part of a community of scholars who are expected to share their data so that other researchers can verify their results whereas applied researchers often work outside of scholarly communities and their data are considered proprietary until or unless they forego this right.

In sum, the economic nature of biological materials and research is quite complex. From a static perspective, biological materials and some research products have a mixed investment character with particular economic characteristics: NHBMs are common pool goods, and HBMs, EBMs, and research products are private goods. However, research is an economic process that transforms bundles of goods with one set of investment characteristics into goods with other characteristics and depending upon institutional conventions, these characteristics may further change over time. Moreover, research may also change the investment character of the assets it employs, e.g. research may transform

a quasi-specific asset, such as an HBM, into a specific asset, such as an EBM that can be used to treat a particular condition for a particular group of individuals. Finally, the costs and returns to basic research are allocated differently than for applied research.

3: Market Exchange in the U.S.

HBMs have been collected, used, and stored for more than 100 years in the U.S. by a wide variety of individuals and organizations: some institutions have archived specimens of human tissues that are more than 100 years old.[5] Stored tissue samples have historically been used by biomedical specialists for educational and basic research purposes. However, in recent years HBMs have played a major role in understanding and treating diseases such as cancer, heart disease, and HIV/AIDS.

Despite long experience, there is no central database of information about acquiring, using and storing HBMs in the U.S. In the late 1990s, the National Bioethics Advisory Commission (NABC) commissioned the Rand Corporation, a non-profit research institute, to report on research involving HBMs.[6] This report was subsequently extended to document information about tissue storage in the U.S. and provides the basis for the analysis in this section.[7]

[5] Eiseman and Haga (1999). While dissections for medical study were carried out in ancient Greece as well as during the Renaissance, it wasn't until the advent of cell theories in the early 19th century that the study of HBMs took hold. By 1912, scientists had demonstrated that cells could be kept alive indefinitely if proper conditions were maintained.
[6] See NABC (1999).
[7] See Eiseman and Haga (1999).

At publication in 1999, Eiseman and Haga estimated that there were more than 307 million tissue specimens from more than 178 million cases stored in the U.S., accumulating at the rate of more than 20 million cases per year. Extrapolating, we can assume that there are at present more than 700 million human tissue specimens stored in the U.S.

Tissue collections range from large, formal repositories to small, informal collections stored in a researcher's freezer. Repositories exist in the public, private, and philanthropic sectors. The U.S. military houses two of the largest tissue repositories in the world in the Armed Forces Institute of Pathology (AFIP): the National Pathology Repository and the DNA Specimen Repository for Remains Identification. These two repositories store more than 30% of all the tissue specimens in the U.S. Other federally funded repositories include the 24 research entities supported by the National Institutes of Health, which is probably the largest funder of tissue repositories in the U.S., the National Institutes of Standards and Technology, and the U.S. Environmental Protection Agency.

In addition to federally-funded HBM collections, there are state collection agencies, research universities and academic centers, pathology departments at graduate medical education (GME) teaching institutions, diagnostic pathology and cytology laboratories, commercial enterprises, and independent non-educational research organizations.

The most common source of tissue is from patients following diagnostic or therapeutic procedures: 52% of all HBMs in the U.S. are pathology specimens. Tissue specimens may also be taken for forensic purposes during autopsies or by voluntary donation. The AFIP National Pathology Repository, GME teaching institution pathology departments, and newborn screening laboratories house more than 75% of the diagnostic and therapeutic specimens in the U.S. Tumor registries, which are cancer data systems that provide follow-up care to cancer patients, may also collect specimens that may be used for educational and research purposes.

A few large repositories have been established specifically for research. In addition, large longitudinal studies collect and bank samples from their participants, and other biomedical research creates tissue collections or contributes to tissue banks. These collections represent about 38% of the HBMs in the U.S.

The remaining proportion of HBM specimens in the U.S. are collected and stored for a variety of reasons. Blood banks collect blood products primarily for transfusions; organ banks collect organs for transplants; DNA banks collect and store tissues for criminal investigations and remains identification; sperm, ovum, embryo, and umbilical cord blood banks store specimens for donation or future use.

Each HBM specimen can be stored in multiple forms including slides, paraffin blocks, formalin-fixed, frozen tissue culture, or extracted DNA. A common use of stored tissues has been to correlate changes in the structure or appearance of a tissue with the diagnosis

of a particular disease. As our understanding of science has advanced our need for biological information has increased but tissue analysis has been reduced to a smaller scale. Molecular biology and genetics research has minimized the need for viable tissue. Frozen tissue, paraffin blocks, or formalin-fixed tissues are sufficient for studying protein and gene expression and genetic mutations. Similarly, a single slice or a million cells is now more than sufficient for research. Hence a single freezer could store a life-time of research samples on a particular tissue or disease.

The areas of research that regularly use tissue samples include studies of gene or protein expression, analyses of tissues affected by a newly discovered viral or bacterial pathogen, studies of changes in genetic sequences over time or over different populations, genetic linkage studies, and analysis of cell structure in affected and normal tissues. Older tissue collections make it possible to study changes over time as environmental and social conditions change, and large sample numbers are required to achieve statistical significance. The ongoing need for HBMs for research and the scarcity of time and money makes it imperative that we achieve efficiencies in finding particular tissues and doing biomedical research.

However, before we can analyze the efficiency of exchange, we must first understand the structure of exchange. The structure of the U.S. market is quite large, very fragmented, and exceedingly complex. Table 2 shows the types of tissue repositories in the U.S. in 1999 and the proportion of all specimens housed by each type. In addition, there were

about 51 tumor registries in 31 states.[8] We can narrow the analysis by focusing on the sources of HBMs for research. In 1999, the primary sources were (1) large tissue banks, repositories, and core facilities, and (2) pathology specimens.

Large tissue banks, repositories, and core facilities, which house more than 39% of all HBMs in almost every sector of the scientific and medical communities, are the major source of HBMs for biomedical research.[9] In 1999, there were over 80 facilities located in 31 states and the District of Columbia including 5 federal government facilities, 55 research universities and academic medical centers, 21 independent non-educational enterprises, and several commercial enterprises. Figure 5 shows the structure of these research collections.

Pathology specimens are collected from individuals and housed in every state in the U.S. by more than 640,000 laboratories and other facilities including GME programs, DNA diagnostic laboratories, clinical laboratories, and the Centers for Disease Control and Prevention Institutes. To be accredited, laboratories must comply with the federal Clinical Laboratory Improvement Amendments of 1988 (CLIA) as well as state regulations. Most patients sign a general consent stating that after completion of any diagnostic tests, some of the sample may be used for research purposes. Although pathology specimens may be used for research, the vast majority are not.[10]

[8] It appears that just a few of the larger tumor registries collect specimens that may be used for research and so they are not included in the summary in Table 2. For information on these registries, see Eiseman and Haga (1999).
[9] Eiseman and Haga (1999) pg. 11.
[10] Ibid, pg. 99.

Further narrowing the focus of analysis to research-oriented exchange with and among large tissue banks, repositories, and core facilities still leaves us with a very complex economic and institutional structure that includes public, private, and club goods, and federal rules, state rules, a diverse set of organizational rules, and the rules and conventions of a number of different scientific research disciplines. And because HBMs are produced, provided, and studied by human beings, individual, family and community rules are as important as the formal rules and rule-making processes of governments, organizations, and professional societies.

4. Governance

Theories of exchange in institutional economics hypothesize that the nature of economic activity determines the nature of transacting, which determines the most efficient form of governance.[11] Williamson proposes a theory of efficient market exchange that is based upon minimizing the costs of transacting. Transaction costs, which are the sum of the costs of executing, safeguarding, and implementing an economic agreement, are a function of the investment characteristics of a transactional asset and the frequency of interaction among the parties to a transaction.

Williamson's theory of efficient market exchange, which is replicated in Figure 6, proposes three types of governance mechanisms for market exchange: market or classical contracting, trilateral or neoclassical contracting, and relational contracting. Market contracting applies to complete exchange between autonomous parties that is not likely to

[11] See for example Coase (1960, 1937), North (1993), and Williamson (1985).

result in any disturbances *ex post*. The theory predicts that market contracting is the most efficient form of governance for transactions that involve assets with non-specific investment characteristics, regardless of the frequency of interaction among the parties.

Trilateral contracting applies to incomplete exchange in which the parties to the transaction maintain autonomy but are dependent because of the difficulty of anticipating the outcomes of transacting. Some form of judicial or administrative-ordering is required to handle unanticipated disturbances. Trilateral contracting is the most efficient form of governance for transactions that occur on an occasional basis and that involve assets with mixed or very specific investment characteristics.

Relational contracting is privately ordered incomplete exchange in a quasi or non-market mode that is participatory, adaptive, and self-regulated: judicial or administrative-ordering serves as recourse when self-correcting mechanisms fail. The relationship itself may be lateral or unified under a hierarchical structure such as a firm. Relational contracting is the most efficient form of governance for transactions involving assets with a mixed investment character that require repeated interaction between the parties. It is also the most efficient form of governance for transactions involving assets with very specific investment characteristics and both occasional and repeated interaction.

The first step in applying the theory of efficient market exchange is to analyze the frequency and the investment characteristics of the transactions involved in exchange. The discussion of HBMs and biomedical research in Section Two suggests five general

types of transactions: 1) obtaining HBMs, which is a transaction involving a Subject and a Researcher; 2) obtaining funding to do research, which is a transaction involving a Researcher and a Funder; 3) doing research, which is a transaction involving multiple Researchers; 4) developing an invention, which involves a Researcher(s) and an Entrepreneur; 5) obtaining a financial return on an invention, which is a transaction that involves an Entrepreneur and a Consumer. Table 3 summarizes the analysis.

In the first type of transaction, a human Subject supplies tissue to a Researcher for research on an occasional basis. In this transaction the researcher seeks a specific type of tissue however it is not clear at the time of exchange what the researcher will learn - if anything - from analyzing the tissue, or what the implications of the analysis may be. And the Subject, because of health, privacy, or ethical considerations, may have an interest in how the Researcher handles both the tissue and the information gleaned from analysis. The theory predicts that this transaction is best governed by trilateral contracting in which third party-ordering can mediate between the interests of the parties until the transaction can be satisfactorily completed.

The second type of transaction, in which a Funder provides finance to a Researcher to research an idea, has the same investment and interaction characteristics as the HBM transaction and is most efficiently governed by trilateral contracting. Both parties are interested in developing an idea but the transaction has some degree of uncertainty and disturbances are possible: third-party ordering is required to facilitate complete contracting.

In the third type of transaction, a Researcher transacts with other Researchers on a recurrent basis to transform an idea into research products that conform to professional research standards. The theory predicts that this transaction is most efficiently governed by relationship contracting: the investment character of the transaction is mixed, there is a high degree of uncertainty, and transacting requires lateral participation and adaptation.

Similarly, the fourth type of transaction is also most efficiently governed by relationship contracting principles. In this transaction, a Researcher and an Entrepreneur transact on a recurrent basis to transform an idea into an invention that will satisfy market demand and deliver a financial return on the costs of development, production, and distribution.

However, the fifth transaction is most efficiently governed by market contracting. In this instance, an Entrepreneur has successfully transformed an invention into a marketable product and than sells the product to a consumer on an occasional basis. The product has a non-specific investment character that makes it possible for the parties to execute a complete contract without third-party ordering albeit in the shadow of judicial-ordering.

The transaction cost theory of efficient market exchange suggests that HBMs and biomedical research transactions cannot be governed by a single mechanism: efficiency requires a full range of contracting mechanisms. And this prediction suggests an equally full range of property rights and regulatory arrangements. Property rights arrangements include private ownership, collective ownership, and public ownership. Intellectual

property rights arrangements include unrestricted access and use, confidentiality and proprietary information agreements, licenses, and patents. Regulatory solutions include limited regulation, self-regulation, and public-ordering.

The organization of biomedical collection and research in the U.S. appears to demonstrate empirically the theory of efficient governance. It includes market, trilateral, and relational contracting. We can find examples of every conceivable type of property rights arrangement. And regulation runs the gamut from limited regulation to public-ordering, mediated by the rule of law and judicial ordering. While this governance system has not produced comprehensive collections of biomedical materials or research, it appears to have meet public health needs and produce high rates of innovation.

Yet the organization of biomedical collection and research in the U.S. is neither hierarchical nor anarchical: it is an example of a polycentric system, which has many centers of decision making that are formally independent of each other. Looking at examples of polycentric public ordering in the U.S., Ostrom, Tiebout and Warren (1961) argue that these systems can produce goods and services as efficiently and perhaps more efficiently than hierarchical systems.[12] Similarly, Frey (2004) argues that polycentric systems are increasingly important in economic organization, that they are better able to solve problems, and that they are less vulnerable and better able to respond to external threats such as terrorist attacks.

[12] Ostrom (1972) elaborates on this concept and its applications for political and economic organization.

Applying the concept of polycentricity to the organization of biomedical research, suggests the possibility that researchers with complementary interests may form cross-sectoral collaborations that allow them to pool their resources. Figure 7 illustrates the idea of creating a polycentric "club" of research "clubs."

The possibility that biomedical polycentric systems may exist or may be created begs a number of questions such as how coordination occurs (if at all), whether these systems are efficient in responding to a health crisis or competing in an increasingly competitive global environment that lacks common standards and rules, or how such a system could be made to be more efficient.

5: Conclusion

Rapid advances in technology and the life sciences and new threats to public health intensify the demand for biological materials and information about biological materials and biomedical research. However, the institutional economics of bio-exchange are under-researched in our discipline and solutions without an adequate theoretical and empirical foundation are not only doomed to fail, the wrong solution at the wrong time has the potential to harm to public safety.

The economic nature of biological materials and biomedical research includes private, public, and club goods, high risk inter-temporal asset transformation, and a number of different types of transactions that require distinctive governance mechanisms. Over a

century of experience in the U.S. has produced a very large and fragmented system for the exchange of materials and research information: it includes 5 federal agencies with more than 24 associated research units; 55 research universities and academic medical centers; 21 independent non-education research organizations; and a number of commercial organizations. In addition, there are over 640,000 under-utilized sources of bio-material and information. This complexity creates a number of collective action problems that potentially constrain the development of comprehensive research collections and research exchanges and limit the ability to respond to threats or remain competitive in the global economy.

However, theories of exchange in transaction cost economics and political science predict that the most efficient way to organize biomedical exchange is in a polycentric system of diverse of governance mechanisms, property rights arrangements, regulatory solutions, and organizational forms. Governance mechanisms include market, trilateral, and relational contracting principles. Property rights arrangements include private, collective, and public ownership, and regulatory solutions include limited regulation, self-regulation, and third party-ordering. Rather than producing an incoherent and fragmented system that inhibits efficient coordination, polycentric systems may actually be more efficient than a hierarchical system, no matter how decentralized.

Further research is needed to test these predictions, examine pricing issues, to identify opportunities to achieve efficiencies by aggregating similar transactions under

polycentric governance systems, and to better understand the strengths and weaknesses of alternative approaches to regulation and third-party ordering.

Table 1: Collecting and Using Biological Materials

Purpose	Practitioner	Educator	Basic Researcher	Applied Researcher	Commercial Service
Advance knowledge	Maybe	Yes	Yes	Yes	Maybe
Solve problems	Yes	No	No	Yes	No
Create new products, processes, applications	No	No	No	Yes	Yes
Develop profitable products	No	No	No	Maybe	Yes
Sell information, materials, or services	Yes	No	No	No	Yes

Table 2: Overview of Stored HBMs in the U.S. in 1999
Compiled from Eiseman and Haga (1999)

Type of Repository	Number of Respositories	Cases	Specimens	Cases Per Year
Large Tissue Banks, Repositories, & Core Facilities	~84	>2.8 million	>119.6 million	390,790
Longitudinal Studies	~9	>340,888	>508,088	-
Pathology Specimens	~640,608	>160 million	>160 million	>8 million
Newborn Screening Laboratories	~53	>13.5 million	>13.5 million	<10,000 to >50,000
Forensic DNA Banks	~48	1.4 million	1.4 million	-
Sperm, Ovum, and Embryo Banks	~50	>200	>9,900	>2,300
Umbilical Cord Blood Banks	~7	>18,300	>18,300	-
Blood and Organ Banks	~233	-	~13 million	~13 millon
Total	~641,092	>178 million	>307.1 million	>20.5 million

Table 3: Biocontracting Predictions

Parties	**Asset**	**Specificity**	**Frequency**	**Contract**
Subject and Researcher	HBM	Mixed	Occasional	Trilateral
Researcher & Funder	Idea	Mixed	Occasional	Trilateral
Researcher & Other Researchers	Idea	Mixed	Recurrent	Relational
Researcher(s) & Entrepreneur	Invention	Mixed	Recurrent	Relational
Entrepreneur & Consumer	Product	Non-specific	Occasional	Market

Figure 1: Taxonomy of Consumption Characteristics, Property Rights, and Governance

Source**:** Margaret Polski (2005).

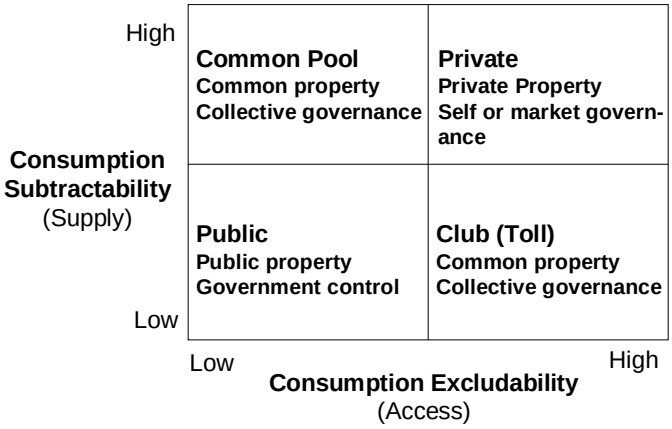


Figure 2: The Economic Nature of Biological Materials and Research Products

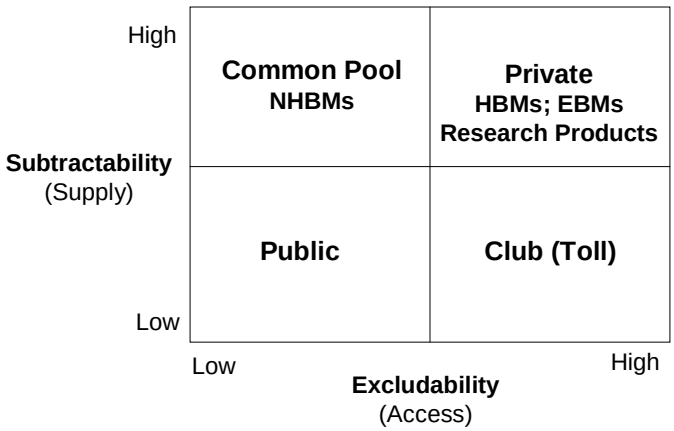


Figure 3: Economic Nature of Basic Research

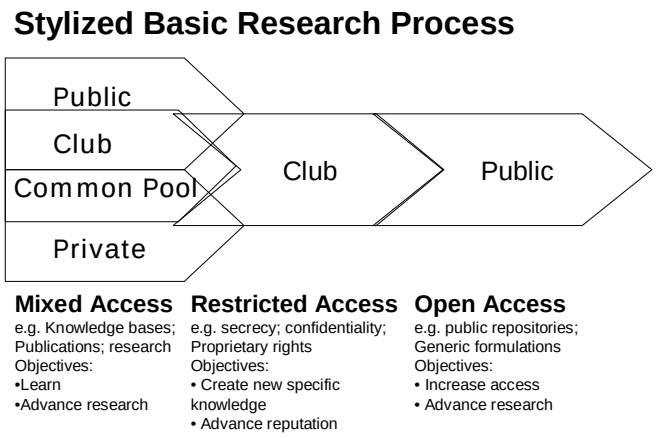


Figure 4: Economic Nature of Applied Research Process

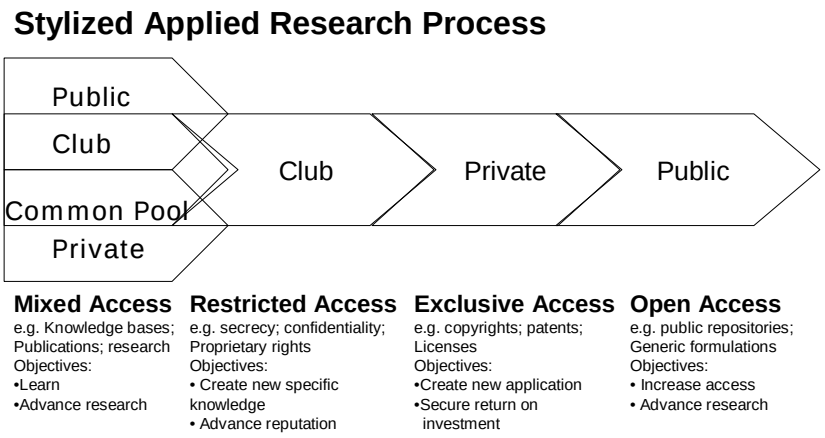


Figure 5: Large Tissue Banks, Repositories, and Core Facilities in the U.S. in 1999

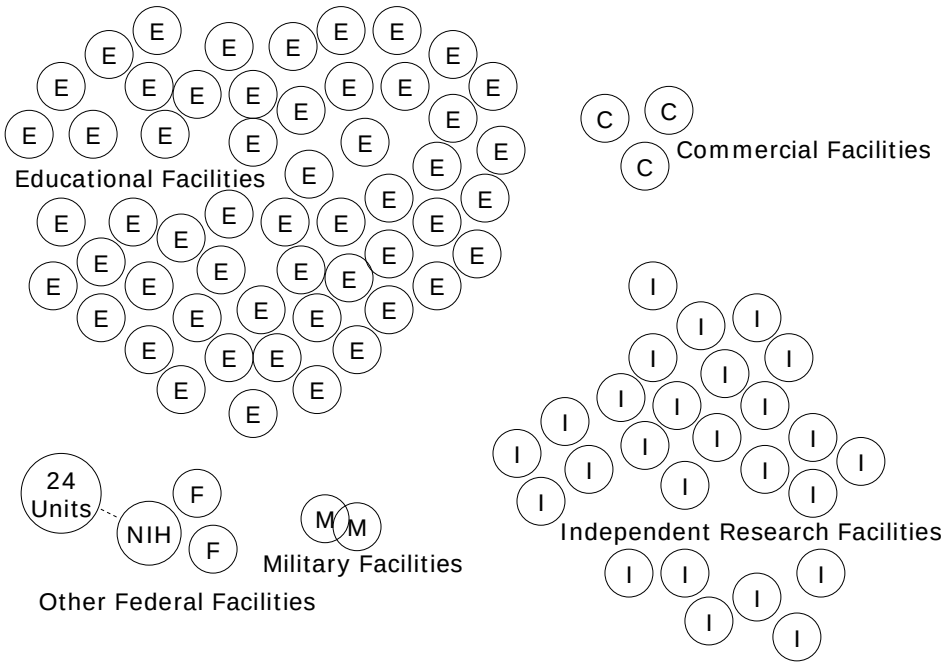


Figure 6: Efficient Governance of Biomedical Transactions

Author's adaptation based on Williamson's theory of efficient governance (1985).

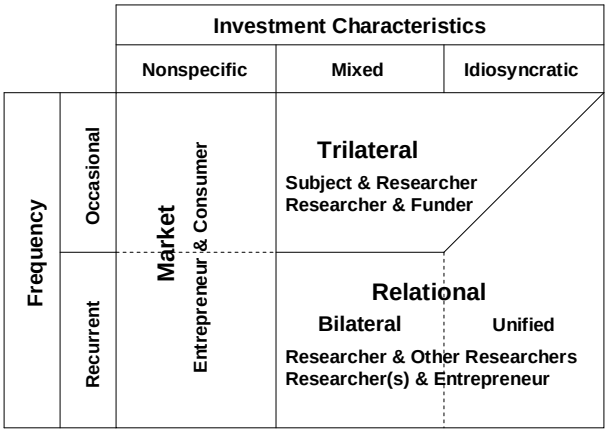
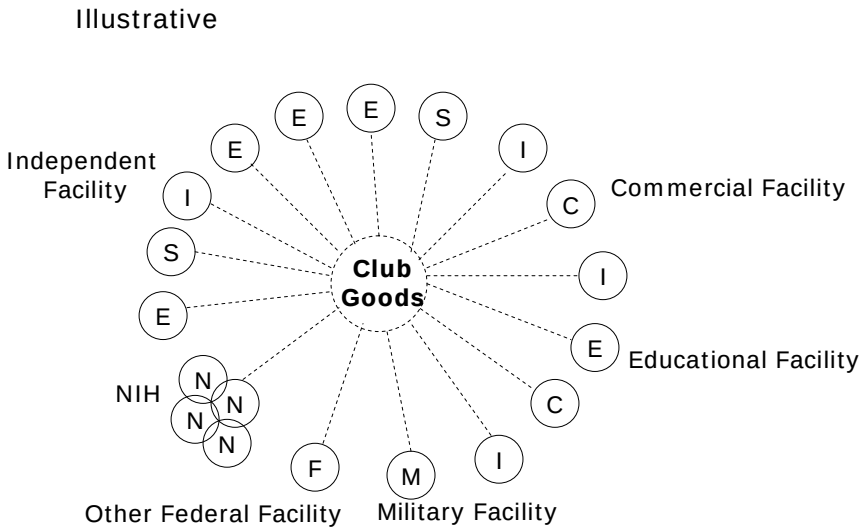


Figure 7: Polycentric Organization of Biomedical Research Materials



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