An empirical analysis of ex-situ conservation of microbial diversity

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Abstract

In this paper we aim to explain a hitherto little analysed issue of biodiversity conservation, namely conservation policies for microbes held in ex-situ collections. Microbes constitute key inputs for basic and applied research and product development. In this context microbial ex-situ collections provide both tangible biodiversity and intangible information. Yet it is not well described what determines microbial collection's conservation strategies. There may be reason to believe that recent changes in the collections' financial and technological context alter and even threaten the conservation priorities of some collections. To bring further light on these issues we explore which factors lay behind the choice to conserve different levels of ex-situ biodiversity with regard to microbes. To this end we begin by locating microbes along the private – public axis in order to gain further understanding of the factors that affect incentives for conservation. Then economic theory of in-situ conservation is brought into the ex-situ context. Micro-level data based on interviews and a worldwide survey with staff of microbial collections is subjected to econometric analysis. Preliminary results support the hypothesis that a social planner would have a special role with regard to conserving a higher level of ex-situ biodiversity.

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1. Introduction

Microbes, thanks to their metabolic activities, have been collected and stored for basic research at least since the 1900th century (Winter and Adam 2001), and in the 1940s the pharmaceutical industry also started to conduct microbial research (Baker 1940). Currently, this biological material serves as a strategic input to the biotechnology sector, which emerged in the mid 1970s (Arora et. al. 2005, OECD 2001). The continued dynamism of the biotechnology sector is illustrated by that its US stock market value increased tenfold over the past decade, to about USD 500 million.[1] The following example from one kind of users of genetic resources (GR), namely the crop development industry, illustrates how ex-situ collections in general have an important role as providers to research given their supply of both new and existing material; survey results from crop development organisations show that nearly 83 percent of their crop research is based on existing cultivars while only 6.5 percent is derived from new cultivars and 2.2 percent from mutation as the only technologically feasible alternative.[2] However, nearly half of all new material from these two categories (4.1 percentage), comes from ex-situ collections (Swanson 1997).[3] Indeed, in this example the use of ex-situ collections for new material is larger than both in situ and induced mutation. In this context ex situ facilities act as important agents in the production chain, as intermediaries which link providers with users in different locations and time periods. As an example of the number and proportion of microbes held by different institutions, ex-situ facilities in the UK hold 280,000 microbes of which up to one third is held in public service microbial collections and the rest in either industry, universities or individual researchers' collections.[4] In parallel with this surge in demand for biological resources ex-situ collections have been subject to increasing financial pressure from

[1] This refers to research oriented biotechnology firms as opposed to firms that market consumer products, such as large pharmaceutical companies (2006).

[2] In the continuation the concepts 'microbial collection' or 'collection' are used to refer to what biologists name public service culture collection. Such collections of microbial cultures have in most cases got a strong historical or current link to public organisations. It is distinguished most clearly from industry in-house collections. Section 3. Case study description contains a further description. Public service culture collections are often members of the World Federation of Culture Collections.

[3] Note that also new inputs are vital: the seemingly low number for new cultivars does in fact correspond to the fact that the crop development industry requires to renew at a annual rate of eight percent. This only emphasise the importance for technical innovation of both new and already described GR (Swanson 1997).

[4] Note that reference may use another distinction between public service collections, universities and other organisations than the one applied in this paper.

governmental donors. The context for ex-situ collections has thus changed dramatically during the last decades.

In this paper we explore the research question of what determines conservation strategies for one kind of ex-situ collections for GR, specifically, public service microbial collections. The approach is supply oriented; while both supply and demand factors influence the conservation choice, information from preliminary surveys and pilot questionnaires indicated that collections traditionally have been, and still to a large extent are, governed not by demand incentives that depend for example market forces but rather by planners in the public sector through long term mandates constrained by yearly budget allocations. Nowadays even collections that are more commercially oriented often at least partly reports to a fundamental social planner mandate.[5] Such social planner may take the form of a public or semi public organisation such as a state department, a university or (public) hospital. However, although starting from a low level also more commercial incentives are gaining increasing influence over the collections.

The subject of our study, public service collections, may perform many activities, but this paper focuses only on their activity regarding the maintaince and conservation of their given stock of microbial GR. Theory suggests that the social planner to be more likely than private industry to commit resources to long term investment projects. Instead, industry would focus on maximising the probability of a hit, that is to find a property that is being searched, of a new commercial innovation in the short run in order to recuperate the investment and thus satisfy its stock owners (e.g. Evenson 1976, Gollin et al 2002, and from different angles, Weitzman 1992 and Swanson & Goeschl 2002).[6] Using this unique dataset, the preliminary econometrics results support the idea that the social planner has a key role regarding the conservation of biodiversity in the context of microbial ex-situ collections.

The paper is organised as follows: next section reviewes the literature that focus on the factors that affect biodiversity conservation strategies in general. Thereafter follows the theoretical framework in which different approaches to address the challenge of search, innovation and

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5 To illustrate the public sector link we refer to an anonymous interview: one collection in Europe derives only a small part of its funding from public sources. In spite of this it follows the government's suggestion to integrate in its own collection large abandoned sets of microbes that are abandoned from other organisations, even though this is not a cost-efficient practice.

6 The social planner sometimes has an additional, non-product oriented aim, namely to assure continued `existence value: this lowers the discount rate for the social planner as compared to industry: existence value, in terms of conservation for the sole sake of storing natural heritage.

conservation are used to derive a hypothesis about conservation choice for microbial collections. In order to test the hypothesis empirically, survey data from worldwide microbial collections is subjected to econometric analysis. The paper ends with the interpretation of the results, provides some policy implications and suggests new research avenues.

2. The marginal value of biodiversity

Biodiversity holds several sorts of values which give rise to different temporal characteristics and user patterns. Swanson (1995) distinguishes between four basic types of global biodiversity value. The first, value of conversion of land, is a static effect that refers to the financial value generated by for example converting forest land to agricultural output. The remaining values have a strong inter-temporal component: firstly, biodiversity conservation is valuable as it spreads risk in the same way as portofolio investment; secondly, the 'quasi option' value arises as biodiversity loss is irreversible and it may hold characteristics that are known but that in the future, through increased research, would show benefit for that is unknown today; and finally, 'exploration value' which refers to previously unknown characteristics that become valuable by time through for example technological or biological innovation. A clear incentive failure with regard to biodiversity conservation that creates inefficiency, thus arises when an individual manager is able to appropriate only the value of the conversion of land, for example by selling timber, while the remaining associated components of biodiversity often fail to provide sufficient short term value to motivate market induced conservation at the socially optimal level.

Partly inspired by the increased use of GR for applied technologies and thus for direct commercial value, during the 1990s a new debate emerged as to what extent markets can contribute to finance the socially optimal level of conservation of world wide biodiversity. Although the positions are divided, a growing concern is that the economic value of GR is too low to allow a market solution to the conservation problem. For example it has been suggested that industry and research alike are interested in only narrow subsets of GR characteristics, as opposed to biological diversity *per se*. This confronts the ideas such as those by Pearce and Puroshotaman (1995) who calculated a high aggregate value of the Earth's biodiversity. The problem being that the marginal value of biodiversity, even at the species level has repeatedly been found to be insufficient to expect a market solution to the conservation problem (e.g., Simpson, et al, 1996). This debate has been enriched. Swanson (1997) suggests that progress in biotechnology is relaxing the technological constraints to information transfer, thus increasing the usability of biodiversity and as a consequence increasing the value of such resources.

Similarly, the estimates by Simpson et al were challenged by Rausser and Small (2000), who argue that a softer assumption need to be applied which acknowledges that pharmaceutical firms and other biodiversity users do not regard as of the same value all facets and components of biodiversity, but instead apply a targeted approach. As a consequence the probability of finding a commercially useful biological compound may be higher. However from the point of view of the original holders of biodiversity there are other economic considerations: for Third World suppliers the value of GR may not be sufficient to motivate other than land conversion, especially since communities' income needs are often too urgent to allow for the both uncertain and longer-term benefits expected from research and development processes. Regarding societal conservation priorities, Weitzman (1998) also highlights that genetic variability, not only sub categories of taxa, is highly valuable since it provides continued access to GR for differentiated needs. To sum up, while conservation does indeed support the progress of research, the estimated marginal value of biodiversity varies strongly depending on the assumptions of the models used, time horizons and user categories concerned.

Goeschl and Swanson (2002) provide a useful theoretical framework which ties together the analysis of many of the conservation incentives at stake. They extend the analysis of the underlying market imperfection structure and model the interaction of two dynamic factors, ecological and technological innovation, respectively. The problem is framed in a context of agricultural production, in which the land owner chooses to either conserve land or convert it for intensive agricultural production. Both choices have implications for final agricultural production output, as follows: on the one hand, conversion to agricultural land generates crop yield that translates into consumption and thus direct use value in the short run. Conserved land, on the other hand, contains GR. Such resources constitute a stock of information that may be used as input to basic and applied research and consequently stimulates the arrival rate of innovations that can enhance welfare in the future. Furthermore, since the conserved land is not exposed to new production technology, such as the sowing of newly developed crops, there is no biological response to applied new technological innovations. Consequently conserved land as compared to converted land implies a lower rate of biological adaptation to technology, such as crops with resistance to pests and pathogens. The land use problem filters down to a choice between support of today’s or future’s consumption. The social planners’ marginal value of land associated with biodiversity conservation is derived, with the core component of the net present value of the increase in agricultural productivity. In this context, the social planner’s discount rate is a composite rate that incorporates both the rate of technological and biological innovation. The aggregate net benefit is represented by the step-size of innovation. Consequently the marginal value of conserved land and thus associated with biodiversity arises from the technological innovations that would be lost if the genetic resource base were narrowed. This framework also allows to think of in-situ conservation as generating welfare benefits not only in terms of providing research inputs, but also by decreasing the rate of biological innovation.

When the valuation debate is brought from the in-situ to the ex-situ domain new factors need to be considered. Firstly, while ex-situ storage of biological resources is indeed a form of conservation, it removes the GR from the biological innovation processes. Secondly, concerns have been raised regarding the user value of ex-situ resources since some are only seldom accessed by private users (Gollin et al, 2000). Thirdly, there is an ongoing property right debate concerning that GR ought to be held either in-situ or ex-situ, and regarding compensation mechanisms to original holders, especially in developing countries.[7] Based on the first and second criticism, several authors have argued that ex-situ collections are of questionable value.

However, two factors of special consideration are inter-temporality of research and the reproducible nature of a biological resources as both may increase greatly the social benefits of innovation if all future users are considered, for example in the plant breeding industry (Day-Rubinstein and Smale 2003). In order to further investigate the strength of the critique Gollin et al (2000) develop a valuation model and test it on data from ex-situ collections for wheat. They find that under certain conditions the value of such crop gene banks is indeed high. The main reason is that searches, even if performed only seldom, can solve problems of a large economic implication, such as a global outbreak of a plague affecting wheat crops. Furthermore, they estimate the value of expert knowledge of for example an ex-situ collection personnel who provides aid to the search for useful traits. That researcher contributes to both reduce the search cost for the client and to increase the probability of a hit of desirable traits or its integration and creation of a new crop variety. To sum up, their estimated value of marginal crop GR held in the ex-situ collection is significant even under conservative assumptions about the benefits that new crops may generate (Gollin et al, 2003). Lastly, the optimal scale of a search is highly sensitive both to the dimension of the economic problem and to the probability distribution of the desirable trait. Also, the search cost and time lags from search to applied technology have a significant impact on the marginal value of biological material held ex-situ. It is thus important to acknowledge that a low frequency of searches and high uncertainty of hits are impediments to a market solution.

[7] Another benefit of in-situ conservation is that a positive incentive for conservation can be channelled to the very holders of biodiversity in southern countries (Swanson 1995).

Building further upon the in-situ versus ex-situ debate, equity concerns have been raised regarding that ex-situ collections often use biodiversity from southern countries to solve the industrialised countries' problems, rather than to address the South's own problems (Shiva, 1997). One example of an ex-situ facility that addresses an exclusive developing country concern is the International Centre for Tropical Agriculture (CIAT) which stores 450,000 accessions of cassava (Epperson et al., 1997). Adding to the in-situ versus ex-situ debate, Epperson et al., (1997) compare the cost and benefit of the two conservation alternatives. Based on CIAT data they estimate the cost of worldwide cassava ex-situ holdings to USD 24 million, partly due to but they recognise that the value is very high of such holdings due to the millions of consumers of the crop and which may benefit from improved crop traits. The same authors estimate that the cost of ex-situ holdings are 53 percent higher than corresponding in situ conservation, but suggests that the largest cost savings are to be made at the ex-situ side, by avoiding duplication of accessions. In this sense it would appear that both in-situ and ex-situ conservation have an important role to play to sustain present and future human welfare.

A third strand of the literature which has contributed towards the analysis of governance of biodiversity, and especially of microbial resources, builds upon the insights from the public-private good analysis.[89] Dedeurwaerdere (2007) explores institutional rules for microbial data sharing for research, and the different properties of the information content of microbe stocks. He notes that such information can be a pure public good, that is, non-depletable and non-excludable, or depletable, when considered as a unit of a flow of information. Also, information in the form of research findings can certainly take club-good properties since they can be held secret or their applications restricted through patents. The question then is how to organise the information sharing at early stages of research, and the diffusion of applied research technology.

Hess and Ostrom (2005) have addressed the issue of the historical tendency towards increasing privatisation as a basis to explore how the theory regarding governance of natural resources can be applied to analyse scientific commons, for example microbes. They set up evaluation criteria regarding the outcomes of the system of users of digitalised information content of microbes.

[8] For the purpose of this paper we use Polski and Ostrom's (1998) definition of governance: 'Governance has to do with humans trying to find ways of making decisions that reduce the level of unwanted outcomes and increase the level of desirable outcomes'.

[9] Economics theory shows that private property rights is a required element in perfect competition (Gravelle and Rees 1992). Other forms of property rights give rise to market imperfections, i.e. situations in which the market mechanism cannot be relied upon to organise transactions in an optimal way, due to for example free riding behaviour with subsequently reduced incentive to invest.

One of their conclusions is that it is costly or even impossible to set up physical or institutional ways for exclusion of such scientific commons. They also note that the way actors interact in the commons strongly affects the success or failure of the resource. In particular rapid change is a common major challenge for systems.

Cook-Deegan and Dedeurwaerdere (2006) have recently explored how scientific commons help to solve problems about the provision and use of knowledge, especially as related to the information content of genetic resources. With reference to recent cases they note that basic research is the principal producer of such commons. Furthermore, they note that there are many different ways to organise the property rights aspect of digitised information in microbiology. For instance, one such provider of genetic information, the Global Biodiversity Information Facility (GBIF), uses a decentralised mechanism by which each data provider to GBIF set the conditions for the wider use of the data. Another information facilitator known as 'Micro-Organisms Sustainable use and Access regulation International Code of Conduct' (MOSAIIC), regulates the acquisition of information through formal material transfer agreements, aimed at providing traceability and fair benefit sharing to the data provider. The authors contend that the common property status can indeed be motivated from a private investment perspective and exemplify this with well known practices such as by the pharmaceutical company Merck when it contributed to create scientific commons in the human genome project. In that way the authors highlight that the key challenge lies not in privatisation per se but rather in the underlying incentive structure. This implies that solutions are to be sought in appropriate rules, norms and institutions.

To conclude, the literature provides different angles from which to estimate the economic properties and value of biodiversity, with resulting insights about different actors' strategies for GR management. In the ex-situ context, it has been showed that the marginal value of GR can indeed be substantial. However, market solutions to the conservation problem are repeatedly hindered by common good properties and other factors such as uncertainty about the value of a marginal unit of biodiversity that imply that market forces alone would under-provide the necessary incentives for a socially optimal level investment in GR conservation,.The lion share of contributions is based on theoretic modelling with well defined players, as well as a few empirical approaches based on search theory. Considerably less effort has been directed to analyse settings with less strict definitions in terms of the public-private borderland. In particular, it is still relatively little known what drives microbial collections' conservation choice. This paper aims to contribute to fill this gap.

3. Microbial ex-situ collections

This section provides a brief introduction to the functioning of microbial collections as well as to some aspects of the increasingly commercial context under which they operate. Ex-situ biodiversity facilities specialise on an myriad of resources, including crop genetic resources, botanical plants, fish and, microbes. Microbes are the smallest forms of life, such as bacteria, fungi, algae and yeast. Since long microbes have been used to develop pharmaceuticals such as Penicillin, but they are used in a host of highly different areas, spanning from resistance to pathogens in crops such as maize, potato and wheat, to bioremediation to reduce the impact of marine oil leakages. Microbial collections acquire, characterise, organise, hold, maintain and diffuse living and preserved microbes and their replicable parts (e.g., DNA, genomes, plasmids, viruses) and information about the distribution of their traits. They also hold databases with molecular and physiological information (Arora et al 2005, Sigler 2004).

Some microbial collections act as patent and safety deposits for researchers, firms and other users, and adhere to the Budapest Treaty on the International Recognition of the Deposit of Micro-organisms for the 'Purpose of Patent Procedure' (Winter and Adam 2001). Taken together the aggregate microbial collection community cover a broad spectrum both regarding the size of the economic problem they address, from remedies to minor crop plagues to bird flue, and different probability distributions of desirable traits such as for a hitherto little explored fungi for new cancer medicine. Collection activities can also contribute to conservation, for example by holding microbes that are not exposed to biological innovations in nature and thus can be considered less altered. New technology also increases its (quasi-)option value as the technology to search, or screen biological material is becoming refined and it allows to return to previously searched populations of biological material with the hope of finding previously undetected compounds.[10]

The World Federation of Culture Collections (WFCC) is the largest network of public service microbial collections with close to 500 member-collections. The largest share of these collections are located in Europe (161 collections) and Asia (161 collections), followed by America (North and Latin America) with 114 collections and a lower number in Oceania (43) and Africa (10). Nevertheless, due to the larger size of American collections (2,799 microbes on average), this continent holds a larger number than Asia, Oceania and Africa (the average number of microbes for Africa being only 85). While the largest collection, American Type

[10] Telephone interview: H. Marie-Daniel of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007

Strain Collection (ATCC) holds a very large collection of microbes, an individual academic may maintain a collection of only a couple of strains to sustain his or her own research activities. A winner-takes it all logic contributes to explain that a few collections have concentrated large holdings, such as in the case of the Dutch CBS; a collection that has discovered new species and acquired the corresponding type strains will automatically be referred to in all publications that make reference to those strains. This in turn will attract new competence to that collection, with a subsequent increase in the probability to find further new species.[11] The largest aggregate holdings of different kinds of microbes are, in falling order and with the approximate number of different microbes in parenthesis; bacteria (450,000), fungi (380,000), virus (10,000) and others (290,000).[12] This signals a high differentiation in scale and scope among microbial collections.

In a broader context public institutions constitute a research structure in which academic researchers and others enrol in research that produces basic research.[13] In our case the innovations are new species, i.e. the characterisation of a hitherto unknown microbe sufficiently different from a know species. The result of this characterisation is known as a 'type strain'.(TP) [14] The diffusion of TPs and other strains builds on reciprocity by which the researcher, upon characterising a new species, needs to keep a proof of the discovery. This proof is the biological material of the microbe itself.

However the storage of microbes is a difficult and costly enterprise that requires competence in terms of expert knowledge, and resources in terms of sophisticated storage equipment such as nitrogen freezers. The publicly funded microbial collections respond to this need and receives TPs against the benefit that they can use them to derive new strains for their own or others' research and commercial purposes. A logical sequence is that individual researchers aim to publish their discovery, and that the specific journals require them to deposit an evidence of the research finding, in this case, a microbe sample, in a microbial collection. It is common practice that more popular journals require the deposit to be held in a microbial collection with a

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11 Telephone interview: F. Van-Hove of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007

12 Information from internet site: WFCC portal accessed in December 2005, http://www.wfcc.info/

13 A scientist of Institute Pasteur expressed the traditionally public mandate oriented scientist position, by emphasising that the aim of scientists should be to maximise the number of microbes in stock as well as their characterisation and finally diffusion. Correspondence, March 2007: F. Bimet of Institute Pasteur, France.

14 'Type strain' is often the isolate of a species that was first discovered and characterized by the "name" giver: used as "reference" for any further research.

distinguished track record of high quality and strict criteria to accept strains. Hence, a microbial collection can be compared with a peer reviewer of a journal which helps to provide scientific quality. [15] [16] Among individual researchers, sharing of microbial information is conducted on a reciprocity basis. For example, a microbe can be provided in exchange for a citation in a scientific journal. [17] As such medium and large size public service, microbial collections tend to be substantially integrated in a broader research network or infrastructure.

The search process for specific properties and functions of microbes proceeds as follows: First taxonomists screen different units of microbes from differentiated sources. Upon discovery of a unit with useful properties, they collect isolates of that unit from different contexts such as different substrates, e.g., soil and water and geographical regions. For example, when exploring the characteristics of a particular cholera bacteria Thompson et al (2003) used ten well characterised strains and 96 isolates, i.e., microbes which are very similar to the well characterised strain. They may keep five that are representative of different substrates and five representative of geographical regions. If it is a newly discovered species, one of these 10 representatives would be selected as being what is called a type strain.[18] Then, the taxonomists characterize microbes in the microbial collection to describe their structure and to find appropriate media upon which to make a microbe survive and reproduce. Increasingly the taxonomist's work borders biochemistry with the use of costly DNA sequencing of microbes. [19]

An example from crop breeding may throw light on the research processes also for microbes. Traits such as plant size and height are be normally distributed. However other traits such as resistance to pathogens and diseases are not, and these are only found in very few accessions (Gollin et al., 2000). The research process to gain information about such traits can be performed in the microbial collections or by outside users such as academia or industry. In both cases, however, a microbial collection may provide important value added in terms of organising the taxonomic information it holds. Regarding genetic resources they are generally used differently by the pharmaceutical and the agricultural research industry. The former tend to use the information contained in the genetic resource, often with great genetic distance between

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15 Personal communication, February 2006; Belgian culture collection representative.

16 For example in the above mentioned research about a cholera virus, the resulting paper made a note that the microbe in question was deposited in the BCCM/LMG collection at Ghent university.

17 Interview, March 2006; Dr. Pierre-Alain Fonteyne, the microbial collection BCCM-IHEM in Belgium

18 Telephone interview: H. Marie-Daniel of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007

19 Interview, 2006, taxonomist Dr. Matthew Ryan, UK based microbial collection CABI the two compounds and without integrating the biological material as such in the research output. Instead, agricultural crop enhancement research uses the biological material as such, from closely related species, to transplant into new varieties (Swanson 1997).

Many collections increase their stocks partly as a consequence of mergers.[20] The most frequent source of funding for microbial collections is public funding, closely followed by universities. To a much less extent the collections receive support from semi-governmental organisations, industry, and auto financing. [21] [22] In addition, while strains used to be distributed for free, a growing number of collections are now charging a fee to cover some of the costs of their operations. Figure 1 shows a large range of fees, from USD 20 to more than USD 400 and also confirmed by the study by Baker (2004) who suggests that the cost per microbial sample, i.e. a strain, from ex-situ collections is in the range USD 150-200. [23] The fact that some fees are significantly higher than the average is coherent with the fact that the marginal revenue to from the provision of microbes can sometimes exceed the marginal cost. Partly due to the social planner (e.g., government or university) mandate, it is common practice to charge a lower fee for non commercial users such as public hospitals. [24]

Figure 1: Fee structure for microbial collections (culture collections)

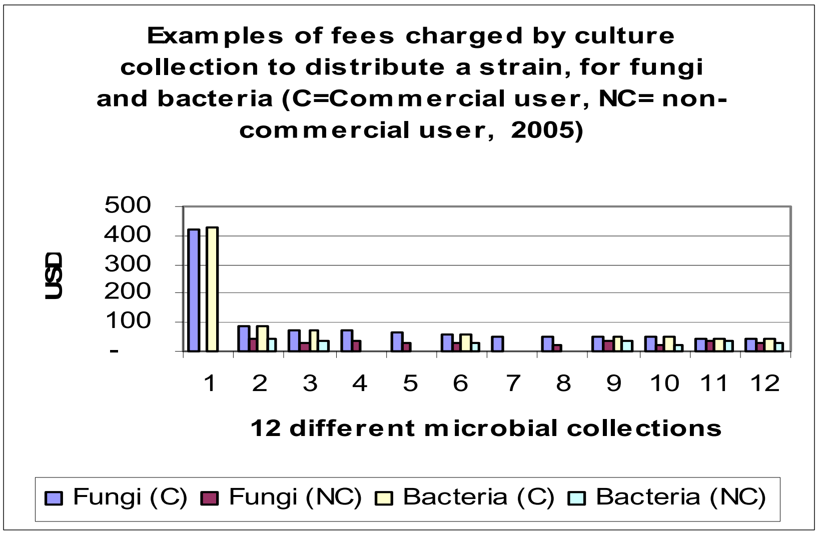
[20] Such increase is also coherent with diminishing returns to search in a given population (e.g. Evenson and Kislev 1976, Rausser and Small 2000).

[21] Information from internet site: WFCC portal accessed in December 2005, www.wfcc.info This information is likely to be based on the principal funding source of collections, and as such only include one of often several funding sources.

[22] However, private companies do invest in public collections via donations of microbes and via foundations and specific research funding. For example a Belgian brewery funds the Belgian yeast collection MUCL to collect yeast strains from the industrial environment for characterization, and another collection has receive expensive nitrogen fridges in donation from a company client. But collaboration can also be motivated by other reasons than to assure steady supplies, for example through a firm's marketing budget; in the pharmaceutical industry firms such as Merck have entered into collaborative efforts with researchers partly in order to increase goodwill among end consumers but also researchers who can be both clients or prospective employees (Cook-Deegan and Dedeurwaerdere 2006, Walsh 2004)

[23] The cost estimate by Baker may refer to both commercial and public service microbial collections.

[24] Another example of commercial influence over the work of taxonomists refers to the naming of newly discovered species: even before it happened that newly discovered species where named after the donors of biological expeditions. However, a recent example of commercialisation is that in 2005, an internet auction gave the highest bidder, a Canadian casino, the right to assign the name to a newly discovered bolivian monkey. The bid amounted to USD 650,000.00 and was channelled to Bolivian conservationists (Economist, Feb 11 2006)



Source: Own elaboration based on prices published on the collections' websites.

Users of microbes can also recur to other sources than public service collections. For example, new technological substitutes such as combinatorial chemistry can partly replace the need for microbial supply. However, the industry needs a continuous supply of microbes, such as the functional information contained in them. In fact, the largest collections are held by the industry itself, including large pharmaceutical firms. [25] However since the second half of the 1990s, shrinking profit margins and mergers among pharmaceutical firms have caused many large pharmaceutical firms to abandon their in-house collections (Baker 2004). This is likely to have affected the public service microbial collections, although the precise impact is yet unknown. For example while microbial collections continue to supply the industry with microbes, at the same time, small niche collections have also started to provide more specialised services to industry. In the light of this change alternative sourcing strategies for the industry have been analysed (Baker 2004). The cost of creating a new collection of 5000 strains to be approximately USD 1 million, without counting the cost items of storage, maintenance and use, which are considerable. [26] It should be noted that if industry needed to reconstruct a collection it would be more expensive to acquire material form ex-situ collections than by creating it from own collections in the field in accordance with the Convention of Biological Diversity (CBD). An alternative for the industry is to source strains from contract service collections, i.e., private firms, for a fee per strain. However, there are both property rights and cost issues involved. A property rights solution could potentially be achieved in order to assure the industry's property

[25] Interview, July 2005: Dr. David Smith of the UK based microbial collection CABI.

[26] Based on that estimate that author suggests that it would be most cost-effective for industry to maintain their own collections, instead of constructing new collections in the future only when their applied research requires new supplies.

rights interest in the acquired strains (Baker 2004), but the major problem filters down to a similar cost issue as in the case of in-house collections. This is the need to assure a sufficiently high and steady flow of revenue in order to maintain the collection. Yet another option is to introduce a private collection within a public collection, financed through a membership fee. However this is not common, and one drawback is that the collection would face financial volatility since firms adhere in a fluctuating way to the support of membership fees to the public collection (Baker 2004). Public support to continued microbe conservation thus appears to be a priority.

In this section we have learned that microbial collections are intermediaries to a large range of users of microbes. These collections provide strains to both commercial and non commercial users, as well as research based on strains, and strains to researchers who then produce knowledge for other users often in a circle that involves both public and private actors. Also, collections lower both administrative and other transaction costs by holding microbes closer to the user, and their knowledge contributes to decrease search cost. Consequently the breadth and depth offered by the aggregate collection community provide a one-stop-shop for traits sought after, and such collections stimulate diffusion of knowledge by holding microbes deposited by many individual researchers in scattered organisations. However during the past decades the basis upon which such collections chose different conservation strategies have received an increasing commercial ingredient. This is the subject of the next section.

4. Decision making of an ex-situ collection: a theoretical framework

This section draws on the different types of values that public and private actors place on biodiversity in order to identify the key drivers regarding the choices of conservation of microbial collections.

An early economic search model by Evenson and Kislev (1976) which in turn extends Solow's (1960) basic research model shows that on one hand markets will under invest in basic research, and on the other hand, the applied research performed by the market itselfmarket's own applied research depends on such basic research. Evenson and Kislev define research as 'search' and model the optimal number of searches in a given population. The aim of research is to maximise the net present value of the output that also includes search costs. Specifically they model the optimal number of searches in a given population, e.g. a crop population, in order to maximise the net present value of that investment. For the industry, such value is measured as profit, while the ideal social planner informs its decision by the broader and longer term concept of social welfare. Technological, i.e. applied, research, can be seen as filling a gap between basic knowledge and applied technology. The larger the gap the easier it is to enhance applied technology, since there would be more 'low-hanging fruit' available in terms of appropriable basic knowledge. For example, in general it is more difficult to improve already high yields, as compared to lower ones. However, the situation is altered if at the same time, the basic research progresses at a high rate, since the basic-applied gap would also be larger. This manifests the nature of the value of basic research also for private industry.

A first implication for our analysis is that the social planner, in order to maximise welfare, would have an incentive to assure high levels of applied research with the aim to induce innovations with subsequent welfare enhancing technology. Industry has an incentive to provide such technology since applied research is easier to translate in short term returns on investment. But since this requires advances in basic knowledge which would not be financially supported by industry at sufficient levels, the social planner would also need to invest in basic knowledge. Indeed, the social planner may invest in applied research too, but since markets may well provide an incentive for such investments, it is the social planner and not industry that would allocate investment to advance in basic knowledge.

Regarding the drivers to different conservation strategies, we refer to three interventions that can stimulate investment in applied research: (i) an increase in the variance of the searched population, (ii) a decreased interest rate since this stimulates investment in general (iii) and, increased basic knowledge (Evenson and Kislev, 1976). As such, given the microbial collections' role as providers of scientific input, they form a key role in the interface between basic and applied research, by linking public sector mandate to policy outcomes.

The second implication for our analysis is to build on the first intervention to create a measure for a microbial collection's contribution to applied research, namely increasing the variance of microbial populations.[27] Evenson and Kislev distinguish basic from applied research in the following way: on one hand, the applied researcher has to its disposal a given population, i.e. cannot change its parameters, and performs only testing. On the other hand, the basic researcher can change the entire population. In this way we take Evenson and Kislev's definition that basic research alters the population searched, and note that moving the parameters for breadth may have the potential to provide larger changes in taxonomic diversity as compared to altering depth. This can be exemplified by recalling the case study example about how a taxonomist's

[27] Microbial collections undertake also the third activity, increased knowledge, through taxonomic and other research. However the analysis of that part is outside the scope of this paper.

search for a desired microbial property may include as many as 80 different kinds of microbes; after all these 80 have been analysed, a public collection keeps virtually all those 80 microbes, that is both depth and breadth, while a private collection will typically only keep the only one microbe that turned out to satisfy the purpose of the study, and, those units that are taxonomically close to it. In that way one criterion to distinguish between more public and more commercially influenced collections is to note that taxonomic breadth is associated with keeping different species. This is akin to to the idea of focusing on biodiversity. Instead, taxonomic depth is associated with keeping different isolates (units) of a given species, hence focusing on variability within one species rather than across species.[28] As an example of a collection with breadth, the Belgian collection MUCL reports that a lion share of its distribution of microbes represents horizontal diversity not vertical depth. For example, in the 1992-2007 period only five percent of all its public and private clients requested the same strain more than once a year while the strains that were provided represented only 22 percent of all the strains of the collection.[29] This example illustrates a conservation strategy whereby breadth is hold irrespective of short term external demand. In terms of Evenson and Kislev's framework this can be interpolated to argue that 'broader collections' are closer to basic research whereas 'deeper collections' are better associated with applied research. In sum, the design of conservation policies in the context of microbial collections balances the inter-temporal capacity to support innovation. Explicitly, we may think of a collection's choice as one between providing breadth versus depth.

While Evenson and Kislev (1976) use a search model based on breeding, Goeschl and Swanson's (2002) framework analyses a patch of land that can be used either for conservation or productive use. The case of microbe collections may be compared to the latter, in which the collection itself is the investment arena for the choice between the commons (better associated with breadth) or the more private good linked to the idea of depth. In that way essential production inputs such as storage space and other resources of the microbial collection can be seen to be allocated in the continuum between breadth and depth.

The classification of a good along the public-private axis is most appropriately based on its use (Cornes and Sandler, 1996)). As such it is possible to think about a complex item such as microbes and their information as the full spectrum of either a private, public, common pool or

[28] Telephone interview: H. Marie-Daniel of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007

[29] Telephone interview: F. Van-Hove of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007

club good. Indeed taxonomic breadth is an example of a non-exclusive good; part of the breadth is depletable, namely microbes that are not well described (non type strains) or microbes held in industrial collections for bulk screening of properties of uncharacterised strains. Such screening is performed in an automatic way, without knowing the properties of the GR. Since the information content is not immediately reproducible it can be described from political science as a common pool resource which has properties that makes the good non excludable, and either depletable or non depletable (Hess and Ostrom 2005).

Another part of breadth, such as type strains, can be considered non depletable given that the international scientific community keeps these strains in public collections and its information is well defined. In fact, microbiology research would be severely hindered without such genetic well described information because it defines the known species. For that reason, the praxis is to keep their information as a pure public good, in a similar way as an agreed universal technology standard which is non depletable and available to all. Furthermore, taxonomic breadth can indeed be seen as an international intergenerational public good according to Sandler's (1999) definition, due to its international properties and user value as well as its user pattern. These are properties that are associated with market failure in the provision of the good. We can think of taxonomic breadth as commons from a social viewpoint, in contrast to taxonomic depth which is less reproducible and has characteristics of rivalness. This implies that taxonomic breadth is less likely to be supplied by the market in a way that is socially optimal.

The social planner would aim to assure the provision of breadth, partly because the market would under provide it, given its common pool characteristics. Additionally, targeted search is better approximated by search in depth rather than breadth. Thus, we expect that industry will chose not to generate breath itself but rather demand it from microbial collections.[30] At the same time the social planner would be interested in the provision of breadth for several reasons: Firstly, a social planner can internalise domestic positive externalities. For example spin-off effects from breadth, in the form of spurred basic as well as applied research that can increase welfare through increased consumption of goods and services. This, in the long run would cause cost savings in future health budgets or increased tax incomes from an internationally more competitive industry. Secondly, a social planner may face relatively lower costs to internalise

[30] It is also expensive to keep well curated taxonomic breadth: the cost is lower for keeping only the isolate sufficient for screening, while the cost is higher for keeping a well characterized and identified isolate such as a type strain. Clearly it is in the interest of industry to save cost, however, this alone cannot explain why the social planner will provide it instead (Telephone interview: H. Marie-Daniel of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007).

national and international positive externalities such as to create a club good or a common pool resource. In the microbe setting this is exemplified by the free exchange of type strains among certain microbial collections. Such exchange has low cost because it builds on existing research infrastructure as well as a strong component of social capital (Dedeurwaerdere et al, 2006). Lastly, and partly as a consequence of the above points, the social planner would also apply a lower discount rate to its investment decisions since it can afford to wait longer for the return to investment.

As noted by Goeschl and Swanson (2002) the incentive structure of the current patent system further increases the firms' discount rate, since it forces them to recover the cost of the investment in innovation before it is put in the public domain. The example of how the social planner but not industry can exploit advantages from breadth is further emphasised at the international level. There are international positive externalities because type strains have club good properties among a group of microbial collections which, in order to capture the positive externalities of type strains they tend to exchange them for free. This praxis is partly motivated by a global efficiency criteria by which it is suggested that properties of such weight for both basic and applied research and product development should be held closer to the user rather than only in one country's collection. This transaction cost criteria has gained further weight after that new biosafety rules placed legal restrictions on international transfers of microbial material since the end of the 1990s. Non type strains, however, are by practice in principle not exchanged among microbial collections. The exchange system builds on reciprocity, in that it is expected that in some time horizon a received type strain will be compensated with another type strain sent to the original provider microbial collection. For example in Europe non type strains are held in 1.2 collections on average while type strains in up to eight collections. [31]

The value for research of microbial information is of such magnitude that it strongly influences the properties for the physical microbe. This provides the social planner with a strong incentive to assure its provision, now and in the future. For example the taxonomic work performed by microbial collections for both taxonomic breadth and depth provides, among others, the public good in the form of increased searchability. However, when comparing higher and lower diversity, as measured by breadth and depth, respectively, the former arguably has stronger commons properties and other characteristics that is prone to cause market failures. This would thus lead the social planner and the firm to differentiated conservation strategies. By viewing as a firm a microbial collection that is more oriented by a commercial incentive, the following hypothesis is derived regarding the stock of collections:

[31] Personal communication, June 2007, Peter Dawyndt; analysis done by the Straininfo Bioportal software

”*The social planner will have more incentive than the firm to invest in high diversity of microbes”*

The sub-hypothesis treats the flow of microbes from the collections:
“The social planner will not prioritise provision to industry.”

In the next section this theoretical framework is applied to study the patterns of conservation and distribution of microbial resources, respectively.

5. Evidence from worldwide microbial collections

The empirical analysis is conducted in close collaboration with the coordinating organisations of two networks for public service microbial collections, namely the UK based WFCC, and MIRCEN, which is situated in France and has 22 member collections both in industrialised and developing countries.[32] The aim is to increase the knowledge about the operations of microbial collections, located worldwide and with different approaches.

5.1 The data

Given the scarcity of social science literature in the field of microbial collections, the study was initiated with qualitative information to broaden our understanding of the technical operations and underlying incentives of the collections. On-site interviews were conducted between 2005-06 that involved taxonomic experts and managers of microbial collections in the UK, France, Belgium and Mexico, complemented with telephone interviews with collections in Germany and Sweden, among others.

Based on the findings from the interviews, a survey was conducted to obtain quantitative data. The population frame consists of all 499 microbial collections that are members of WFCC or MIRCEN. In order to assure a high response rate a pilot questionnaire was circulated to 12 microbial collections in industrial and developing countries. Based on the pilot survey the final survey instruments were constructed, consisting of three questionnaires designed together with representatives of WFCC and MIRCEN, and distributed electronically with a two months

[32] WFCC is the largest international collaboration organisation for public service microbial collections. MIRCEN, founded and coordinated by UNESCO is another network of such collections.

interval to all the members of WFCC and MIRCEN networks from Europe, Africa, the American continent, Asia and Oceania. Additionally, for the first questionnaire a posted questionnaire and follow-up telephone calls targeted a subset of 170 randomly selected collections stratified by OECD membership of the country of origin. 153 collections responded to the first questionnaire, 117 to the second and 78 to the third one.

The analysis is performed on 103 collections that provided data in the first questionnaire as they answered about questions linked to variables that were expected to be most relevant to explain their conservation strategy choice. Since 51.7 percent of the population and 66.7 percent to the sample were collections based in OECD countries, the sample is somewhat overrepresented in this variable. This should be considered in the interpretation of the results. Annex 1 contains descriptive statistics of the variables used in the regressions.

The survey results allows to illustrate the ways to relate in formal as opposed to informal networks, such as formal property rights and quality signalling.[33] For example the property rights approach taken by a collection may signal its relations with industry. Since collections receive their strains from many sources, a general question was formulated to learn about the they way transfers are regulated. 40 percent of the respondents received their strains through some formal agreement, either through material transfer agreements or similar. However, a follow up question shows that this practice is limited in terms of number of strains that the collection receives: usually up to 20 percent of their strains are sourced in this way, while nine collections obtained between 20-100 percent via contracts. Regarding the legal frameworks at the international level, only 13 percent, have a written policy associated with the mandate of the Convention on Biological Diversity. The earliest such policy among the respondents being from 1995 and the latest from 2006. The number of ISO certificates can also provide some information about the signalling of the quality management regime among microbial collections with only about 13 percent having at least one type of ISO certificate. These results indicate that somewhat formalised ways of dealing with microbes is indeed occurring, but that such practices may be less common regarding sourcing from developing countries.

Regarding the international complementarities in the commons, networking may be an important enabling factor. To gain further understanding of networking among collections, a set of questions was included to reveal membership status in formal collaboration initiatives. 39

[33] The number of survey answers to these questions in particular is too low to allow to include them as variables in the subsequent econometrics analysis

percent of the sample are members of a collaborative network apart from WFCC and WDCM. [34] These networks include ECCO, GBIF, and other largely national and regional initiatives, such as UKNCC. [35] However, membership is much lower in specific voluntary initiatives in quality management, and regarding Access and Benefit Sharing initiatives. In terms of quality management initiatives, only three respondents indicated that they are members of common standard setting initiative, and another three of CABRI, [36] and other less frequently cited initiatives. Additionally five collections are also members of multilateral government agencies. This reveals a complex picture and it implies that there is a host of unused networking possibilities for collections that are willing to take this route to further exploit national and international complementarities among the collections.

5.2 Econometric model specification

The Probit model is designed to deal with dichotomous dependent variables and was thus chosen to explore the determinants to a collection's conservation strategy.

a. Dependent variable for conservation strategy

In the context of microbial collections it is possible to distinguish between the industry's incentive to maximise the user value in the short run, and the social planner who, additionally, has an incentive to conserve diversity based on non-use value, exploration value and option value. As such only collections that are more influenced by social planners, such as governments, have an explicit conservation incentive. Such a collection is also associated with conserve and utilize more biological diversity.

In order to measure the two concepts of 'taxonomic breadth' and 'taxonomic depth' we make use of the organisational classification of microbes known as 'type strains'. All users, including academia and industry, may use both type strains and non-type strains. Specifically the organisational classification 'type strain' refers to strains that represent a species. It follows that a higher number of type strains reflect a higher quantity of species, and since species is a relatively horizontal way of organization based on genetics, it is associated with measuring 'taxonomic breadth'. It also follows that a higher proportion of type strains may signal higher

[34] World Data Centre for Microorganisms (WDCM)

[35] United Kingdom National Culture Collection (UKNCC), a network of several culture collections.

[36] Common Access to Biological Resources and Information (CABRI)

species diversity, and higher genetic distance, because generally genetic distance may be argued to be higher between two than within two species.

Search theory suggests that it is more efficient to target search and therefore it is assumed that industry would prioritize taxonomic depth instead of breadth (Baker 2004).[37] However it can also be argued that industry needs taxonomic breadth, for instance in order to screen species that it lacks in its own 'in-house collections' and would thus source it from a public provider when needed. Since the majority of microbial collections charge a handling fee even when it is well below the cost of holding and maintaining a strain, this can be seen as a de facto subsidy.

Here we proxy different conservation strategies by focusing on the proportion of a collection's microbe holdings that are type strains and non-type strains. We include the dummy variable , "*RATE_10"* which denotes if the collection, in this case a general purpose collection, holds more than 10% type strains in its stock. The threshold is chosen in order to distinguish collections with higher breadth from those with higher depth. To test the robustness of the results with respect to the chosen threshold, other specification of the variable were tested.

Collections' resources are limited in terms of financial resources, for example personnel, storage space and other maintenance costs. Thus at the margin, an increase in either type or non type strains implies the opportunity cost of forgone benefits from storing less of the other kind of microbes. Other factors also limit the possibilities to acquire type strains. For example path dependency in the form of reputation and being part of networks among collections and with other providers of type strains. These factors may constitute fixed costs. Taken together type strains are often more costly to acquire and hold than non type strains.

To sum up the collection manager faces the choice between providing different levels of taxonomic breadth and depth with limited resources. The dichotomous variable *rate_10* reflects such discrete choice. In terms of the theoretical framework, type strains represent a collection's taxonomic breath strategy associated with a future user value while non-type strains represent user value today. The choice can be described as a utility maximisation problem by a

[37] Type strains are demanded also for their own properties, namely they are accompanied with documented information such as origin of the strain, genetic structure and requirements for reproduction. However, they are also much less proprietary in that this information is widely disseminated in scientific channels such as journals but also websites. As such they cannot be the base for patents and it follows that their explicit commercial value is limited. Rather, culture collections and other users such as industry use type strains as a reference to compare strains that have been analysed outside the culture collection.

representative collection manager subject to resource constraints. A series of factors intervene in the conservation decision, such as collection characteristics and the geo-economic context.

b. Main explanatory variable

In order to test the hypothesis that a social planner has a higher incentive than a firm to conserve a higher level of microbial diversity we focus on the underlying incentive structure of the collection. Taxonomic breadth versus depth in a microbial collection may depend on various key aspects that are explained below.

Collection with heavy public funding are assumed to better be able to stock a broader collection, since the market alone would tend to under-invest for such conservation strategy. Similarly, a collection only based on private funding is more likely to depend on revenue generated from the industry. Hence, such collections are assumed to stock a 'deeper' collection, since this is what will provide a higher revenue given its demand from the private sector. The majority of collections are located somewhere in between these two extremes and would consequently represent a continuum of breadth versus depth.

Since breadth is costly and subject to market imperfections, collections with a higher proportion of breadth can be expected to perform in a way that is closer to a collection with with full public funding, and more depth to be closer to a full private funding collection. As such a collection that is more influenced by a public mandate is expected to conserve a higher proportion of taxonomic breadth. To measure the level of influence that a social planner has on a collection we use the categorical variable "*PUBL_81"*. It denotes whether a collection derives most (more than 80 percent) of its funding from public institutions.[38] Traditionally such organisations have created and maintained microbe collections, which reported to mandates stipulated by public donors.

As mentioned, increased financial pressure on public donors has been paralleled with the biotechnology boom having leveraged the commercial interest in microbial collections. This

[38] The variable corresponds to the questionnaire question 'Of the funds that the collection had to its disposal for spending in 2005; approximately how much came from public bodies (as opposed to private)?', and the answer 'above 80 %. The other categories are: Nothing, Up to 20 %, Between 21-40%, Between 41-60%, Between 61-80%. The highest category was chosen as the threshold for the variable, because we wanted to distinguish those public service collections that are still very much financially dependent on a social planner, from those that are not.

has pushed some collections to be more commercially oriented. The two effects exercise both financial stimuli and a restraining incentive. The source of funding is expected to have a major influence over the conservation strategy. A majority of the collections in our sample have heavy public funding. We expect a higher adherence to a social planner mandate in such collections, and high public funding is a requirement to be able to prioritise type strains.

c. Control variables

We include other variables to control for other factors that may also affect the conservation strategy, and as such are expected to enhance the interpretability of the parameters associated with the main variable publ_81, which is the basis of our first hypothesis. The control variables are the following ones:

- *"PROV_PRI"* indicates the proportion of a collection's supplied microbes that are provided to industry, as opposed to distributed to other users such as academia or teaching. [39] It is similar to *publ_81* in that both are included to indicate the public-private orientation of the collections. It is expected that *prov_pri* would affect the dependent variable "*rate_10"* positively in the following since on one hand industry needs breadth, but will not invest in the associated costly production and maintenance process. Instead industry will only produce and hold own depth. Consequently industry needs to source breadth from other holders, such as public service microbe collections. On the other hand the social planner, who aims to maximise social welfare, will address also industry's needs for breadth, and this will be reflected in a conservation strategy that satisfy what also industry need to generate well fare enhancing applied technology.

- *The variable "STRAIN"* stands for the aggregate stock of type and non type strains. This variable, *strain*, is included since the scale of the collection is also likely to affect its composition. That is, a collection can be more conservation oriented in real terms, i.e. by having a large stock of type strains, but since it may have a much larger stock of non-type strains the composition may not indicate species diversity. As such the variable *strain* represents the dilution effect as non –type strains are in general are relatively much more abundant in the collection. A larger collection is expected to have a lower proportion of type strains. [40]

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[39] The potential presence of bias between *prov_pri* and *rate_10* is analysed further below.

[40] The effect of stock on type strains can also be thought to be positive since larger scale may signal competence and resources, something that enables to have many type strains. However the dilution works in the other direction and is expected to be stronger.

- The dummy variable "*OECD_MAX"* indicates whether the collection is located in a OECD country or not. This explanatory variable builds on the idea that OECD countries reflect higher domestic industry demand for microbes for instance from the biotechnology industry. To this end the OECD countries Mexico and Turkey are coded as non-OECD, and Brazil, China and India coded as OECD. The variable may be ambiguous to interpret since it contains other information than industry demand, such as financial wealth of the country. We expect that OECD countries in general have a higher proportion of research collections (more private investment in Biotech) as compared to general purpose collections that prioritise type strains. A link is expected between OECD membership, size of the collection, and the composite effect of these variables on the composition of the collection. To address this issue the variable is also interacted with the variable "*strain*".

- "*ECCO_ISO"* is an interacting variable that is included to measure the joint effect of club membership and a collection's competence level. Specifically, a collection's competence is expected to influence the conservation strategy, since different conservation strategies may require different levels of general ability in terms of human resources and gene flow infrastructure, such as domestic and international sourcing networks. In this respect ISO certificates are awarded only to organisations with high quality standards in technical as well as administrative processes. ECCO (European Culture Collections Organisation) is a network of 41 European microbe collections. Since our indicator of diversity (or taxonomic breadth), associated with type strains has club good properties in the sense that transfer of type strains among collections requires social networks, it is expected that collections that form part of networks are more likely to create and maintain such networks. Thus it is expected that ECCO membership will affect positively the ratio of type strains in stock. Both ISO and ECCO aspects are interacted.

- *"RECE_CC2"* is a categorical variable that indicates whether the collection sources strains from another collection. This variable is included as there is a rule of conduct among microbe collections which stipulates that all exchange among microbe collections are to be done only with type strains rather than non-type strains. Hence, it is expected that sourcing from other microbe collections increases the likelihood of a higher type strain ratio in a given collection's stock.

5.3 Industry orientation model

An additional Probit model is estimated to complement the conservation choice analysis and address explicitly the sub-hypothesis regarding a collection's decision regarding industry orientation.

a. Dependent variable for industry orientation strategy

In order to test the hypothesis that a social planner would not prioritise provision to industry we use the variable "*IND_YES"* to represent the flow of microbes. Specifically, it represents the dichotomous choice of a collection regarding whether to provide any strains at all to industry or not. The variable reflects the flow of both type and non-type strains. As noted before, the industry turns to collections to obtain strains and for research. As such the flow of strains to industry from a collection with high proportion of type strains often consists of either direct orders from industry of type and/or non-type strains or, strains delivered as part of the results from contract research. This *IND_YES* variable reflects such flows, and represents the outcome of the decision to provide strains to the industry.

b. Main explanatory variable:

We build on the analysis from the theoretical framework and use the same specification for the main explanatory variable as in the first regression. As such it is expected that a heavily social planner oriented collection, represented by the variable "*PUBL_81"*, is less likely to pursue an industry oriented strategy, i.e. to distribute strains to industry.

c. Control variables:

- *"TYPE_STR"* indicates the number of type strains in stock. [41] [42] Since industry needs strains and services from collections with expertise in taxonomic breadth, this variable is expected to have a positive effect on the decision to provide to industry. [43]

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[41] In order to represent the scale effect instead of the proportion of type strains, in this specification the continuous *type_str* is used instead of the dummy variable *rate_10*.

[42] Specification tests are discussed in section 6.1.1 Specification tests.

[43] A collection with many type strains will attract industrial customers, since it is expensive for companies to invest in the kind of basic research capacity that is identification services (Telephone interview: F. Van-Hove of the Belgian collection BCCM/MUCL (Agro)Industrial Fungi & Yeasts Collection, 7 May 2007).

- *"FEE"* is a dummy variable that reflects whether a collection charges a fee when supplying strains from its collection, as opposed to distributing the strains for free. It should be noted that the applied fee regime does not necessarily signal commercialisation or a *de facto* industry orientation, but rather that the collection has decided for a industry orientation policy or not. A prior review of pricing policies shows that the fee regime is applied both by collections that provide to industry and collections that provide to other users. In particular, the data for the year 2005 shows that incomes from strains are indeed often very low, sometimes null. While it could be thought that any user would prefer not to pay fees, our interviews suggest that this is not the case. Indeed, the fee variable is expected to affect positively the demand from industry, in the following way: often fees are so low that they are not an obstacle for industry, however, a collection that charges a fee signals that the collection is more commercially oriented and may thus offer lower transaction costs for industry to deal with. As such fee status signals policy rather than income. [44]

- *"PROV_ACA"*, indicates the proportion of distributed strains to other than industry sector, especially to academia and hospitals. It is expected to be negatively associated with industry orientation sign since it already represents a non-commercial orientation. [45]

- *"OECD_MAX"* reflects the OECD membership of the collection's host country and it is expected to positively affect industry orientation because it also includes various countries beyond the OECD that have a strong biotech industry, and thus higher domestic demand from industry.

- Lastly, the variable *"STRAINS"* is included since it is perceived that the size of the collection may affect industry orientation. However, no particular sign is expected for the

[44] For this reason endogeneity is not expected, i.e. it is not likely that the actual supply to industry will cause the collection to take the decision to start to charge a fee, only the other way around.

[45] Note that *prov_aca* is continuous (and censored), while the dependent variable *ind_yes* is dichotomous. Also, the collection can provide a percentage also to other users than industry and academia. For these two reasons there is not a mutually excluding relationship between the two. For example it is possible to think about a collection policy that is oriented towards academia, but which also acknowledge industry's demand for some of its strains. Such kind of collection would have both a higher probability to have a higher relative distribution to academia and to provide to industry.

variable as such, although very small collections are less likely to have the capacity and competence to supply to industry. [46]

Table 1: Description of the variables used in the econometrics analysis *

Variable	Description
Dependent variables	
RATE_10 (1st model)	The collection holds more than 10% of strains as type strains
IND_YES (2nd model)	The collection provides strains to industry
Explanatory variables	
PROV_ACA	Percentage of the distributed microbes that are provided to academia and hospitals
PROV_PRI	Percentage of the distributed microbes that are provided to the private sector
STRAINS	Number of strains in the collection's stock (type strains and non-type strains)
PUBL_81	Of the funds that the collection had to its disposal for spending in 2005, more than 80 percent came from public bodies (as opposed to private donors).
STRAIN_OE	Interaction variable: number of microbes in stock*the collection is a OECD_MAX collection (see definition of oecd_max in this table)
TYPE_STR	Nr of type strains in stock
Dummy variables	
ECCO_ISO	Interaction variable: collection is member of ECCO

[46] It was also expected that ISO certificate will enhance the likelihood of providing to industry. Such certificates are commonly seen as an asset for any company that wish to signal a high level of quality in the market. As such several collections have gone through the quality certification process that leads to the granting of an ISO certificate. While culture collections traditionally has operated in a context of close networks among researchers and collections, the recently emerged industry interest in microbes calls for a mechanism that can signal quality to actors also outside of such networks. The ISO certificate system is one such mechanism. However our data presents problem for econometric model since there are no observations for the combination of *iso* = 0 and *ind_yes* =zero, and as such the variable cannot be included. Nevertheless this result is in itself useful since the strong link between *iso* and industry supply supports that competence is an important factor to industry supply.

	which is a European network of microbe collection, and, has an ISO certificate which is a quality certificate
FEE	The collection does charge a fee to provide microbes
OECD_MAX	Collection is hosted by an OECD country (excluding Turkey and Mexico, including Brazil, India and China)
RECE_CC2	The collection does source at least some of its strains from another microbe collection, as opposed to from academia, hospitals, own sourcing, or other.

* The values correspond to the year 2005

6. Results

6.1 Conservation strategy

The conceptual framework has highlighted the different values posed on genetic resources by different users, in particular between private and public actors. The following analysis explores if these conclusions are valid in the context of microbial collections.

The regression for conservation choice (table 2) supports the hypothesis that collections that are more influenced by a social planner are more likely to invest in taxonomic breadth. That is, the variable that indicates an influence of a large public investor in the individual collection, *PUBL_81,* is associated with a significant and positive coefficient in the probit model thus indicating that it affects positively the likelihood for a high type strain ratio in stock. [47] The data indicates that a collection with heavy public funding is more likely to have higher breadth as compared with a collection with less than 80 percent public funding. This result supports the hypothesis that a social planner will prioritise investment in the commons which in the case of microbial collections this is represented by taxonomic breadth. It also suggests that although public service microbe collections traditionally rest upon a social planner mandate, this mandate works through the actual financial influence that the social planner exercises on the collection.

[47] To test the robustness of the result for the *publ_81* variable to different specifications of the dependent variable, the 10 percent the ten percent threshold was replaced with a five and fifteen percent type strains, and, *rat_mid1*, a dummy denoting if the collection belongs to that half of the collections in the sample that had more than 4.3% type strains in stock. The results were very similar for most of the variables, with same sign and mostly same significance levels. However with *rat_mid1* the variable *publ_81* increased significance to well above the 95 percent level, while *publ_81* was not significant with the five and ten percent thresholds. This suggests that the results should be interpreted as tentative.

The flow variable *PROV_PRI* is also associated with a significant coefficient with the expected sign. The effect is large; compared with the sample's average share of distribution to industry, a one percentage unit increase in *PROV_PRI* causes an estimated increase of 61 percent in the likelihood of having more breadth. As noted above, the analysis is based on a supply oriented view of the functioning of microbe collections. As such this result supports that collections that decide for an industry orientated distribution policy, as reflected by the higher proportion of distribution of strains to industry, have a higher likelihood to invest in maintaining a high proportion of type strains. It follows that since industry output can contribute positively in terms of social welfare enhancing technology, the social planner would support industry with taxonomic breadth. As such a collection that prioritises industry distribution, reflected by a high proportion of strains provided to this sector, is likely to prioritise what the industry's demand, i.e. taxonomic depth.

Table 2: Maximum likelihood estimates of the probability of having high diversity of microbes (Probit)

Variable	Coefficient	Marginal probability	Robust Standard Errors
PUBL_81±	2.036553***	.1636251***	.0887994
PROV_PRI	.5551413*	.6146221*	.1680496
STRAINS	-.0007845**	-.0002368**	.0000862
OECD_MAX±	-1.009603***	-.3550754***	.1879361
STRAIN_OE	.0007566**	.0002283**	.0000864
ECCO_ISO±	1.714186*	.6085966*	.1793058
RECE_CC2±	.333718	.0954774	.0891797
CONSTANT	-.5897193		.5404704

No. of observations: 103

Wald chi2(7) = 28.53 Prob > chi2 = 0.0002

Pseudo R2 = 0.2358

± Regarding marginal probability for this variable: is for discrete change of dummy variable from 0 to 1

z and P>|z| are the test of the underlying coefficient being 0

* significant at 99 percent level, ** significant at 95 percent level, *** significant at 90 percent level

Regarding *STRAINS*, *OECD_MAX* and *STRAIN_OE* are included as interacting variables. Thus we focus on the meaning of the interaction variable *STRAIN_OE* alone, not on its components *STRAINS* and *OECD_MAX*. The negative effect that larger stock of strains has on the type strain composition is larger for a non-OECD collection than for an OECD collection. [48] One interpretation is that while an OECD collection will have a lower composition of type strains, and so will a larger collection, the dilution effect is larger for a non OECD collection. Based on the sample's average number of strains, one additional strain in a non-OECD collection will decrease the type strain composition with 0.02 percentage points. This would imply that for 1000 additional strains in stock, the composition of type strains would decrease with 20 percentage units.

The dummy interaction variable *ECCO_ISO* is significant and has the expected positive sign. This suggests that a collection that is a member of the ECCO network and holds an ISO certificate is associated with a higher likelihood of being more focused on type strains. ECCO membership provides increased access to the type strains of the ECCO network, i.e. ECCO members benefit from the club good status granted to type strains by ECCO members, but the effect is increased if the collection has an ISO certificate, since this signals competence and quality in technical and administrative processes. Lastly, the sourcing variable *RECE_CC2* is not significant. However its positive sign is consistent with the idea that collections that receive strains from other microbe collections are more oriented towards type strains.

The results of the model provide some preliminary support for the hypothesis that social planners would set high diversity as a conservation goal. Further, the result of the model is consistent with the idea that type strains have club good properties.

Specification tests

a. Overall fit:

The Wald test is 28.53 with a p-value of 0.0002 and informs that the overall model is significant as compared to if no explanatory variables where included in the model. [49] The goodness of fit measure Pseudo R2 is 0.2358. The application of the Huber/White/sandwich estimator reduces potential misspecification such as from omitted variables.

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[48] The *oecd_max* which was not significant with the alternative specification of the dependent variable, i.e. fifteen percent type strains in stock.

[49] For an explanation of the Wald test, see paragraph below about bias.

b. Heteroscedasticity:

The dispersion of the number of strains within subgroups may vary directly with the subgroup mean. In other words, subgroups with higher mean number of strains, such as high-income countries, may also exhibit greater dispersion around the mean. This creates the problem of heteroskedasticity. Heteroscedasticity cause the maximum likelihood estimators to be inconsistent and the covariance matrix to be inappropriate, i.e. the values of coefficients will be misleading. A score test with the Lagrange multiplier statistic was applied to test for heteroscedasticy in the variance of variable *strains*, which showed to be present. For this reason the Huber/White/sandwich estimator of variance was applied to obtain better variance estimates and confidence intervals than is the case with the conventional estimator. [50] [51]

c. Endogeneity bias:

A potential problem is the presence of endogeneity bias due to a mutually causal link between *RATE_10* and *PROV_PRI*, i.e. that the attribute variable that denotes a high proportion of type strains, *RATE_10*, is likely to increase the likelihood of a higher level associated with variable *PROV_PRI*, and vice versa. If endogeneity exists, that the resulting estimators will not be consistent or efficient, and consequently they will be difficult to interpret. However in our case both supply and demand factors make simultaneity bias (discussed below) more likely than endogeneity bias. Firstly, the supply approach taken in this paper is based on the perceived strong difference between two kinds of collections: on the one hand the public service microbe collections that are studied in this paper, and on the other hand the relatively recently established private contract collections. [52] Our data is based on the former kind of microbe collections, which in most cases have different degrees of a public service mandate and consequently are still significantly more directed by other than market demand incentives than is the case for the contract collections. As such a demand effect associated with a higher type strain ratio would increase the likelihood of supplying to industry is at odds with the perception of a decision framework that is more influenced by supply factors. Such supply factors are addressed by the variable *PUBL_81*. Secondly, demand for strains from industry and other

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50 This procedure is in accordance with Sribney, B. (1998) Advantages of the robust variance estimator, StataCorp, published on the software STATA's website. Note that if the robust estimator is used in spite of that the model is correctly specified, then the estimates will be less efficient. Nevertheless this ought not to be a problem because the LM test indicates heteroscedasticity.

51 The LM test for the variable *strains* for the second regression, with *ind_yes*, also indicates heteroscedasticity. Accordingly the robust estimator is applied to that regression too.

52 The latter are sometimes even previous industry in-house collections that have been outsourced to private suppliers as a means to enhance efficiency.

users depend on a host of attributes of both the demander and the collections. The interviews held with representatives of collections do not support that the effect of type strain composition alone is an important explanatory variable. To conclude the assumption is that the collection manager is strongly influenced by an underlying public sector mandate, and chooses distribution policy before conservation policy.

d. Simultaneity bias:

Rather than endogeneity bias, simultaneity bias may be present. This is the case if the collection manager simultaneously determines the collection's user orientation and conservation choice. In that case the two Probits can still be estimated consistently by individual single Probit models, however, this would be inefficient in that it ignores the correlation between the disturbances in the two regressions. Specifically, the two error terms contain information that will affect each other in a non random way (Greene 2003), thus violating the assumption of random errors. To address this possibility a Seemingly Unrelated Bivariate Probit is also applied with the dependent variables *RATE_10* and, the dichotomous variable *IND_YES* which represent a dummy variable associated with whether the flow of microbes goes to industry. In this model two dependent variables are included instead of one and the model assumption is that both outcomes are simultaneous, i.e. they vary jointly. The Wald test was performed to test for the null hypothesis that simultaneity exists is not significant at the 10 percent level. [53] Therefore the two Probit regressions are presented separately.

6.2 Industry orientation

The coefficient of the funding variable *PUBL_81* supports the hypothesis that a social planner would be less inclined to prioritise provision to industry. The coefficient has the expected sign, which indicates that a strong public service mandate, as reflected by heavy public funding, goes with an orientation towards other users than industry. A collection with heavy public funding is ten percent less likely to provide to industry than other collections. It follows that collections with heavy public funding do not have a strong incentive to provide strains to industry, indicating that they can also have a higher rate of return from other activities, both in the case of a general purpose collection and very specific public research collections.

[53] In other terms this statistic, like the likelihood ratio test and the Lagrange multiplier statistic, tests for independence between the error terms of the two regressions. The Wald statistic is by the square of the t ratio and is tested with the chi-square distribution (Greene 93). As such the interpretation is that the statistic should be higher than the critical value, which is computed from the degrees of freedom of the numerator and denominator, and the significance level such as 5 percent.

Also the stock variable *TYPE_STR*, i.e., stock of type strains, is significant and has a positive effect..As compared to the average number of type strains hold by the collections in the sample, one additional type strain increase the likelihood of supplying to industry by 0.03 percent implying that a collection that holds 1000 more type strains is 30 percent more likely to provide any strain to industry. This suggests that public service collections with high diversity will indeed provide industry with what industry, due to search rationale and market imperfections, itself will under invest in.

The variable *FEE*, is also significant and supports the idea that charging a fee signals that the collection has adopted a more commercial regime and thus is prepared to serve also commercial clients in a way that suits them, for example with the kind of administrative standards required by certain industry users. Specifically, charging a fee increases the likelihood of providing to industry with 38.7 percent. *PROV_ACA* is significant and with the expected negative effect. That is, a higher proportion of strains distributed to academia signals that for the collection the academia and industry represent two structurally different users. The collection is likely to focus on only one of them, while potentially being more flexible in distributing to other kinds of organisations such as other collections. *OECD_MAX* is not significant, but the positive sign is consistent with the idea that OECD countries have more domestic industry demanders. Finally, the scale variable that denotes size of the microbe stock, *STRAINS,* is not significant implying that a larger stock of strains decrease the likelihood that the collection provides to industry.

One can conclude that collections specialising in distribution to industry use other means than heavy public funding for acquiring their type strains. It is likely that such collections will supply type strains to industry, because industry needs at least some type strains, but if the collection would be heavily publicly funded then they would not provide to industry. For example such collections use financial resources from private contracts, or from fees earned by distributing strains. [54]

Table 3: Maximum likelihood estimates of the probability of distributing any microbes to industry (Probit)

Variable	Coefficient	Marginal probability	Robust Standard Errors

[54] For that aim they may also aim to implement more restrictive licensing policies such as application of Material Transfer Agreements for provided strains. Indeed this is happening for example in the case of ATCC (American Type Culture Collection) which increasingly rely on restrictive use policies as a way to capture the rents from its strains.

PUBL_81±	-.5524683***	-.1064509***	.0656117
TYPE_STR	1.517284*	.0003418*	.0000921
FEE±	.0000205*	.3865388*	.1227078
PROV_ACA	.4195408*	-.2857596*	.1243681
OECD_MAX±	-1.449056	.0960445	.1054178
STRAINS	.0017334	4.04e-06	3.53e-06
CONSTANT	.1549047		.5174197

No. of observations: 103

Wald chi2(6) = 45.96 Prob > chi2 = 0.0000

Pseudo R2 = 0.4428

± Regarding marginal probability for this variable: is for discrete change of dummy variable from 0 to 1

z and P>|z| are the test of the underlying coefficient being 0

* significant at 99 percent level, ** significant at 95 percent level, *** significant at 90 percent level

7. Conclusions

In this paper we have explored for the first time the drivers, at the meso-level, of genetic resource flow, from ex-situ microbial collections. The principal interest is to explain conservation choices for such resources, as expressed through microbial collections' stocks of what we term taxonomic breadth versus taxonomic depth, as well as the question of the distribution to sectors such as the industry. Interviews and a world-wide survey were conducted and the analysis confirms the important role that these collections play as holders and distributors of biodiversity. Specifically, such collection are the basis for distribution of inputs for both basic and applied research, such as in academia and industry.

The econometric analysis of conservation strategies for ex-situ microbes supports previous conclusions from in situ conservation and crop breeding analyses. Namely, consistent with the theory of the commons as well as the theory of search, society rests on public investment for provision of high biological/microbial diversity.

The paper has also analysed how social planners relate to industry. The results indicate that social planners support basic research rather than applied research that is performed within industry. Given the impact of commercial incentives, the different attributes of collections in terms of their underlying incentive structure, directly affect their biodiversity conservation choices. It follows that due to pressure to decrease public spending in general, together with the high commercial interest in microbial resources, social planners are exploring public-private partnerships to assure sufficient funding to sustain actualised stocks and quality of microbes. However, this commercial pressure also causes collections to shift their conservation strategies.

Traditionally, exchange of microbial genetic resources between the scientific community and microbial collections has been governed by informal rules and supported by international institutions such as the WFCC. However, the changes brought about by an increasingly commercialised atmosphere call for a review of this system in order to create the incentives for continued production of not only niche collections but also scientific commons in terms of taxonomic biodiversity (breadth) given the considerable cost to rebuild collections once ceased, and the irreplacability of strains.

This paper provides new insights about the way that public-service microbial collections constitute a very heterogeneous group of institutions. It appears to be key to distinguish between the different underlying incentives of collections, and from that to assure the kind of conservation strategies needed to ameliorate threats from future biological innovations as well as to support solutions to other problems. In this sense policy makers need to assure that the ex-situ collections' conservation strategies take on a measured balance between current needs of applied research at the expense of basic research. As such microbial collections provide different aspects of international common good properties that need public support, from solutions to large scale economic problems in industrial countries, such as wheat plagues, to problems that are more important in developing countries, such as plagues in minor crops such as cassava. Furthermore, supported by the result that international club good properties are related to taxonomic breadth, collaboration appear to be relevant not only nationally, but internationally in order to continue to sustain global complementarity among collections.

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Annex 1: Descriptive statistics of the variables used in the regressions

Variable	Obs	Mean	Std. Dev.	Min	Max
RATE_10	103	.3106796	.4650348	0	1
IND_YES	103	.6796117	.4689076	0	1
PROV_PRI	103	.2260874	.2584254	0	1
FEE	103	.6699029	.4725473	0	1
PUBL_81	103	.5436893	.5005232	0	1
TYPE_STR	103	424.4078	1028.562	0	5768
ECCO_ISO	103	.0679612	.25291	0	1
STRAIN_OE	103	4443.068	11131.19	0	80146
PROV_ACA	103	.5943204	.3364907	0	1
STRAINS	103	4853.495	11139.31	22	80146
RECE_CC2	103	.6990291	.460923	0	1
OECD_MAX	103	.815534	.3897604	0	1