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by

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Benefit sharing mechanisms for agricultural genetic diversity use and *in-situ* conservation.

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Abstract The agricultural genetic diversity is reducing at an accelerating pace. Benefit sharing mechanisms are well-known instruments to incentivize local genetic resource providers to maintain *in-situ* diversity and to avoid free-riding behaviour by multinational bioprospecting firms. We explore the role of these mechanisms in a setting where the output of bioprospecting activities (i.e. a modern seeds variety), competes with traditional agriculture, and the latter is necessary to conserve the genetic pool from which the multinational could extract the resources for developing new modern varieties in the future. We adopt a multistage game where the multinational anticipates the impact of its bioprospecting investments and price settings on the local owner incentives to conserve genetic diversity. We focus our attention on two benefit sharing mechanisms, namely profits sharing and technology transfers, and compare them with a benchmark featuring free genetic resources access. Our main conclusions suggest that incentives to conservation are the strongest under profit sharing, while a technology transfer produces a genetic erosion that is even higher than under free access. These results shed new light on policy design, especially in developing countries where agricultural genetic diversity is a strategic natural asset.

Keywords: bioprospecting, genetic diversity, modern varieties adoption, monetary benefit sharing, technology transfer.

1 Introduction

The bioprospecting is the exploration of biodiversity to find genetic resources with R&D potential for the development of new commercial products (Artuso 2002). It refers to the systematic search for genes, whole organism and valuable natural compounds in wild or domesticated ecological niches

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that can be utilized by botanical, phytomedical, pharmaceutics, agricultural and enzymes industrial production. These sectors heavily relies on biological material as raw input for their market products (Rausser and Small 2000, Yamaura et al. 2017); as a matter of example, it is worth highlighting as the proportion of global sales value derived from biological resources in the cosmetic, pharmaceutical and agricultural seeds industries were respectively equal, in 2010, to 6.1%, 35% and the 100%[1].

In particular, the agricultural seeds sector is continuously searching for genetic material embedded in local and traditional crops landraces in order to extrapolate genetic traits useful to produce modern varieties resistant to climatic extreme events, pests, diseases and, in general, capable to show superior yield potential (Cassman 1999; Shiferaw et al. 2014). Such landraces are the outcome of an evolutionary selection process driven by both local agroecological characteristics and farmers' subsistence requirements (Altieri 1999). The heterogeneity of this selection makes local varieties incredibly adaptable to degraded and poor soils, water scarcity, droughts and biotic/abiotic stresses. This implies the urgency of motivating marginalized and cash constrained farmers, especially in developing countries, to maintain a diversified portfolio of traditional varieties as a strategic asset to face agricultural shocks and climate change (Bellon 2004; Mercer and Perales 2010). Exploiting the ecological services provided by the crop diversification, farmers would not only minimize agricultural risks (Di Falco and Perrings 2005, 2009; Bezabih and Sarr 2012), but would also directly act as "custodians" of local agricultural genetic stock (Panayotou 1994) and, indirectly, as unrewarded suppliers of the genetic inputs for the bioprospecting activity (Pascual and Perrings 2007). Such conservation behaviour would indeed benefit the bioprospecting firms, offering them a very rich stock of traits from which to select the most promising ones in terms of quality and expected returns (Goeschl and Swanson 2002; Baumgärtner et al. 2008; Narloch et al. 2011).

Nevertheless, the diffusion of modern varieties has been recognized as one of the main causes of the narrowing cultivation of traditional varieties, and this implies, in turn, local *in-situ* genetic erosion (Harlan and Wet 1972; Altieri 1999; Pascual and Perrings 2007). This erosion is due to the fact that the new varieties refer to a reduced set of few major cash crop species and are genetically standardized and uniform (Artuso 2002; Perrings et al. 2006). Within this context, the second report on the State of the World's Plant and Genetic Resources for Food and Agriculture highlights that, since the beginning of the Green Revolution, the number of the worldwide consumed crop varieties has gradually decreased and, currently, only four crops satisfy the 60% of the human food energy requirement (FAO 2010). This calls for more attention on the incentives for local farmers to devote land to traditional agriculture (Alam and Van Quyen, 2017).

While it is debated how infrastructural and informational barriers as well as agroecological condi-

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[1] See, for details, OECD 2011, Täuber et al. 2011 Shand 2012.

tions impact on modern varieties ability to boost the marginalized farmers' livelihood[2], it is true that subsidies to their adoption and agricultural modernization reduce the financial incentives to cultivate local landraces; this also happens because the option value related to the genetic diversity conservation is not fully internalized by the markets (Narloch et al. 2011; Krishna et al., 2013). These market failures are linked, more generally, to the common pool resources features of local varieties grown in small rural communities or spread across regions (Polski 2005). As a result, farmers cannot fully appropriate of the diversity value they supply, so that less genetic resources are conserved, as compared to the social optimal level (Heal et al. 2004; Pallante et al. 2016). The free access to these resources is also a crucial driver of the so-called "biopiracy" by multinational bioprospecting firms (Koopman 2005; Bellon et al. 2015) that, conditional to patenting, can also operate as monopolists on the new varieties market (Qaim and Janvry 2003; Ramaswami et al. 2012).

In summary, the bioprospecting industry invests in the development of the modern varieties by *free-riding* on the exploitation of the *in-situ* genetic diversity, but the increasing diffusion of new varieties on farmers's cultivated land is an additional channel that undermines the conservation of the genetic resources themselves, thereby depriving the industry of the stock from which to feed potential future varieties development (Bellon 2004; Kijima et al. 2011).

On the basis of these considerations, the evolution of bioprospecting regulation, and specifically the adoption of the Nagoya Protocol (Protocol from now on) by the Conference of Parties of the Convention of Biological Diversity in 2010, is very welcome. The Protocol establishes a legal framework for the access to genetic resources and for an equitable sharing of all the commercial benefits arising from bioprospecting. In light of the Protocol, the benefits arising from the utilization of genetic resources should flow back to the owner and provider of the genetic resources so as to internalize the positive externalities provided.

Benefit sharing may be monetary or non-monetary. Monetary benefits include up-front or milestone payments as well as royalties[3]. As examples of national legislations applying monetary benefits sharing we can cite, among others, the well known Costa Rican Biodiversity Law that regulates the use of genetic resources growing in indigenous territories provided that an access fee and up to 10% of royalties is paid to the local owner. Another interesting case is the regulation in force in Panama, that covers also domesticated genetic resources whose origin is recognized to be in the national territory. Other than an access contract, the user must guarantee the provider with a free prior informed consent and a benefit sharing agreement binding to the payment of no less than 1% of the net sales (Caprera et al., 2014). India published an official guideline for access and benefit sharing in 2014 (Kohli and Bhutani 2015)

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[2] See, for instance, Isakson 2011, Cavatassi et al. 2011, Erlich and Narayanan 2014, Coromaldi et al. 2015.

[3] Which implies that patent protection is established under international systems as the Agreement on Trade and Intellectual Property Rights (TRIPS) and the International Convention on Protection of New Varieties of Plants (UPOV).

introducing a benefit sharing ranging from 0.1% to 5% of the annual gross ex-factory sale of the new developed product.

Non-monetary benefits include sharing of results of R&D, institutional capacity building, joint ownership in Intellectual Property Rights (IPRs) and technology transfer [4]. According to FAO, the latter is the most used type of non-monetary benefit sharing representing, for istance, 34% of all the projects funded under the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGR). Moreover, 28% of this share consists of transfer of modern seeds to local communities, and 14% is related to improving knowledge and agronomic techniques for utilizing the new modern varieties (Galluzzi et al. 2014).

Over the past decades, the economic analysis has focused on the actual value of commercial R&D based on genetic resources in the bioprospecting industry[5], while only more recently the attention of scholars has turned to the impact of benefit sharing rules on biodiversity conservation, R&D investments decisions and the optimal contracts between providers and users [6].

We add to existing literature by developing a theoretical multi stage game where the effects of benefit sharing mechanisms on the agricultural genetic diversity conservation are analysed in a context where the bioprospecting output, i.e. the modern variety, also represents a feedback threat to conservation. Two economic and ecological trade-offs may arise. On one hand, the farmer provides genetic resources, a valuable input to the bioprospecting firm and, once the access to resources is granted, can decide to purchase and utilize the modern variety developed by the firm or to keep cultivating the local landraces. In the former case, however, genetic diversity conservation effort is reduced. The second trade-off arises according to the bioprospecting firm's incentives. An increase in R&D investments, improving the quality of the new variety, increases profits. On the other hand, the improvement in quality decreases land allocated by the local farmer to traditional agriculture and, implicitly, reduces the conservation effort, with a potential negative impact on future bioprospecting.

To the best of our knowledge, these trade offs have not been stressed in the existing theoretical literature. Our analysis allows us to shed light on policy relevant questions related to the different available benefit sharing mechanisms in terms of their impact on *in-situ* local diversity when the output of the bioprospecting activity is in competition with the agricultural genetic diversity itself, as well as on the bioprospecting firm's decision on R&D investment, when the firm itself accounts for the economic-ecological trade-off related to conservation.

The rest of the paper is organized as follows: in section 2, we present the structure of the model

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[4] The Secretariat of the Convention on Biological Diversity, Nagoya Protocol on Access to Genetic Resources and The Fair and Equitable Sharing of Benefits Arising From Their Utilization, 2011. Montreal, Canada.

[5] See, for instance, Simpson et al. 1996, Goeschl and Swanson 2000 , Costello and Ward 2006, Moschini and Yerokhin 2008, Sarr et al. 2008.

[6] See, among others, Dedeurwaerdere 2005, Gatti et al. 2011, Richerzhagen 2011, Markandya and Nunes 2012, Onofri and Ding 2012, Welch et al. 2013, Polaski, 2009.

while in section 3 results are illustrated. Section 4 presents a comparison of the different policy scenarios and section 5 discusses results and concludes.

2 The Model

We implement a two-stage game with two risk neutral agents: a local farmer (individual or community), owner and provider of the genetic resources and a user of these, namely a bioprospecting multinational firm. In the first stage of our game, the multinational bioprospecting firm chooses the investment in R&D and the price of the modern variety, while in the second stage the local owner chooses land allocation between the traditional and the modern variety. Figure 1 shows the conceptual framework of our setting.

The local farmer manages a fixed size agricultural land on which local landraces are cultivated. The cultivation of these varieties is based on traditional agricultural techniques and implies a certain yield and utility for the owner (1). The bioprospecting multinational (MNE) is interested in exploring the genetic resources embedded in such landraces (2) in order to develop a new modern variety. The MNE defines the level of R&D investments, that affect the expected quality of the modern variety, and the market price (3). These two elements, together with agricultural inputs and experimentation costs linked to the adoption of a new variety, concur in defining the world (4) and the local owner demand. Once the new variety has been marketed, the land allocation decision of the local farmer influences the *in-situ* diversity conservation (5) and the future bioprospecting activity of the MNE, since the higher is local demand, the lower is land allocated to the local landraces.

FIGURE 1 - HERE

In the absence of conservation policies, the MNE only faces costs related to both R&D investments and future foregone profits in case of genetic diversity reduction, but has a free access to the genetic resources (Figure 1, panel a). This biopiracy can be regulated by imposing benefit sharing mechanisms (Figure 1, panel b) coupled with a (lump sum) genetic sample acces fee that has to be paid by the MNE to the owner (6). We analyze the impact of two benefit sharing mechanisms as compared to the free-access case. The first consists in the payment of a share of profits by the MNE to the local owner (7) and the second in a technology transfer that reduces the local owner's experimentation costs of adopting the modern variety (8).

2.1 *Free-access case*

The bioprospecting multinational firm (MNE) decides the level of R&D investments I on the modern variety (MV). The cost related to R&D is equal to $C = \frac{\gamma I^2}{2}$.The investments affect both the global demand for the new crop and the probability that the MV is of good or poor quality. We assume that a MV is always successfully developed and the more the MNE invests, the better is output quality. The MNE also defines the price, P, of the MV to be charged on the world market. The multinational is therefore assumed to have monopolistic power on the world market, as it is recognized to be the case of seeds bioprospecting firms (Qaim and Janvry 2003; Ramaswami et al. 2012).

We normalize the total (exogenous) amount of available land for the local farmer of the genetic resource (farmer from now on) to 1, and label the land allocated to the MV as L. Also, we assume that the land allocated to the MV also measures the demand for it from the farmer. The world demand comprises two parts: the demand from the farmer, i.e. L, and the demand from the rest of the world, labelled as D. As a result, the inverse demand function faced by the MNE is $P = I - W$, where $W = L + D$. Reasonably, the local owner is assumed to act as a price taker on the market for the MV, representing a very small fraction of the world demand (Acharya and Barbier 2000; Lybbert 2006). This also implies that changes in local consumption of the modern crop affects the current MNE's revenues in a negligible way.

In choosing the price P and investment I, the MNE anticipates the variation in the amount of land allocated by the farmer to the MV, and the consequent impact on the conservation of local genetic resources, as measured by the proportion of land remaining allocated to the local landraces once the MV is made available on the market. As will be clarified below, in analysing the farmer's land allocation choice, higher expected quality will increase the world and local farmer demand, while a higher price will decrease it. As a result, the MNE faces a trade-off between the current profits from developing a better MV, on one hand, and a possibly negative impact on the value of expected future profits, due to genetic diversity erosion, on the other.

Thus, in the fist stage of our game, the MNE sets I and P to maximize profits Π:

$$\max_{P,I} \Pi = (P(I - P)) - \frac{\gamma I^2}{2} + (1 - L)r$$

where $1 - L$ is land allocated to the traditional variety, which is, in our setting, a measure of conservation effort, while r[7] are unit expected benefits from future bioprospecting which depend on current conservation effort. The unit expected return from conservation is assumed not to depend on the current policy setting, or on current price and investment choices. This assumption limits indeed

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[7] These incorporate both discounted revenues and costs associated to the future bioprospecting and variety development.

the generality of our results, but is not expected to alter their qualitative features.

In the second stage of our game, the farmer chooses land allocation between the traditional and the modern variety. Following the seminal paper of Feder (Feder 1980), the unit revenue obtained from cultivating the MV is subject to uncertainty on its responsiveness and interaction with external agricultural inputs[8]. More specifically, unit revenue from the MV is $y+\varepsilon h$, where y is the mean revenue, h is a term related to output variability and assumed to be positive (without loss of generality), while ε is a random variable with mean zero, dependent on the quality of the MV. We assume that ε is discrete and equal to 1 with probability v and equal to -1 with probability $1-v$ (Feder and O'Mara 1981). It is a clear-cut case which represents "good world" or "bad world" scenarios. The link with the quality of the MV is also assumed as simple as possible: a larger quality, i.e. a larger I, implies a larger probability that the MV turns out to be good, namely we assume $v = I$, so that $1-v = 1-I$. On the contrary, the local landraces cultivation allows the farmer to obtain a unit profit of R with certainty[9].

Two types of costs are identified when a non zero amount of land is allocated by the farmer to the MV. First, P denotes the market price of the MV as established by the MNE. As already anticipated, we assume that the demand of the modern variety has a one to one relation with the farmer's land allocated to it (Bezabih and Sarr 2012; Feder 1980). Second, the farmer faces other agricultural costs related to the use of MV that are, instead, not necessary under the traditional cultivation of local landraces (Di Falco and Chavas 2006). These costs are related, for example, to hiring labour, purchasing chemical fertilizer, increasing weeding and tillage requirements (Teklewold et al. 2013; Dercon and Gollin 2014) and are assumed to be increasing and convex in L : $c\frac{L^2}{2}$, with $c > 0$. It follows that the farmer, taking as given the market price and the expected quality of the MV, chooses the amount of land to be devoted to it with the aim of solving the following expected utility maximization problem:

$$\max_L E\left[U\right] = L(y + Ih - (1-I)h) - c\frac{L^2}{2} - PL + R(1-L) \tag{1}$$

$$s.t. L \leqslant 1. \tag{2}$$

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[8] Financial uncertainty on the response of a new modern variety is dependent by the fact that the farmers has never utilized it. Moreover, the modern varieties are expected to outperform the traditional ones if their cultivation is joined with modern agricultural practices that involve the use of chemical fertilizers and pesticides at an optimal rate unknown at the beginning by the farmer (Evenson and Gollin 2003; Byerlee 1996)

[9] We here exclude the uncertainty on local landraces yield potentially caused by climatic shocks, pests, diseases or droughts. These shocks are exogenous and likely to have an adverse expected impact on both landraces and modern varieties. On the contrary the MV yield uncertainty is caused by the already mentioned unexperience on the use of new variety and is idiosyncratic to this (Munshi 2004 ; Koundouri et al. 2006).

2.2 *Monetary benefit sharing*

We model a monetary benefit sharing mechanism as a binding payment by the MNE of an access fee *plus* a royalty to the farmer, in order to compensate him for the cultivation of local landraces and the conservation of valuable genetic resources. The access fee is intended as a lump-sum transfer or a milestone payment and is denoted by $T > 0$. A share $\beta \in (0, 1)$ of the MNE revenues determines the royalty.

Under monetary benefit sharing, the MNE has additional costs, $\beta WP + T$, and solves the following problem:

$$\max_{P,I} M = (P(I - P)(1 - \beta)) - \frac{\gamma I^2}{2} + (1 - L)r - T \tag{3}$$

$$s.t. L \leqslant 1 \tag{4}$$

The farmer's expected utility increases instead by $S = \beta WP + T$ so that she/he now allocates the land between the MV and the local landraces according to:

$$\max_{L} E[U] = L \cdot (y + Ih - (1 - I)h) - c\frac{L^2}{2} - PL + R(1 - L) + S \tag{5}$$

$$s.t. L \leqslant 1$$

2.3 *Technology transfer*

A non monetary benefit sharing mechanisms may take several different shapes. We are here interested into a technology transfer because, as mentioned above, it is the most applied scheme of this kind in real life. The technology transfer is here intended as a learning process on how to use modern varieties. The literature recognizes the existence of "technological-transitional costs associated with new technologies adoption" (Feder and O'Mara 1981; Sunding and Zilberman 2001). In agriculture, such costs are associated to the lack of initial knowledge by owners, especially in developing countries, on how to make the modern varieties highly responsive on their land and in specific agro-ecological zones (Lipper and Cooper (2009); Coromaldi et al. 2015) and should be conceived as necessary to acquire the technical information related to a profitable cultivation of the MV (Croppenstedt et al. 2003; Conley and Udry 2010). Within this framework, in our setting, such costs are taken as internal in the cost of the MV adoption.

With a technology transfer, the MNE can convey to the farmer a set of "best agricultural practice" information. While the transfer of such informative set does not produce costs to the MNE (Teece 1977), it is straightforward to assume that it allows a reduction in the transitional experimentation costs to cultivate the MV and that this saving depends on the magnitude of a strictly positive parameter $\phi \leq 1$.

Moreover, a high quality MV would imply a larger benefit from the technology transfer to the local owner: indeed, it is reasonable to assume that, together with larger expected revenues, a better MV would also imply a more fruitful "learning effort" from the farmer. Formally, including also the payment of the access fee, we have that owner's benefits are equal to $S = \phi IL + T$. Notice that, given our assumptions, only T enters as a (lump sum) cost into the MNE objective function.

According to the technology transfer cost and benefits, both the (2) and (1) are modified consequently.

3 Results

In this section we show the equilibrium values for land allocation, investment and price under the different modelled scenarios. The game is solved by backward induction. Here to guarantee strictly positive equilibrium values and that second order conditions hold, we assume that $\gamma > \frac{1}{2}$, $h < \frac{1}{4}$, $\beta + 2\gamma - 1 > 0$ and $1 - 4h - 2\phi > 0$[10].

Stage 2: *The farmer's land allocation*

In the second stage the farmer sets L to maximize (1). The corresponding first order conditions require[11]:

$$\frac{dE[U]}{dL} = 0$$

implying the following amounts of land allocated to the new variety under our three scenarios:

$$\text{free-access } (f)\text{: } L_f = \frac{1}{c}\left(2hI_f - P_f - R - h + y\right); \tag{6}$$

$$\text{monetary benefit sharing } (m)\text{: } L_m = \frac{1}{c}\left(2hI_m - P_m - R - h + y\right); \tag{7}$$

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[10] A detailed account of all the assumptions on parameter values is given in Appendix 2.

[11] Second order conditions are straightforward in this case since $\frac{d^2EU}{\partial L^2} = -c < 0$.

$$\text{technology transfer } (t)\text{: } L_t = \frac{1}{c}\left(2hI_t + I_t\phi - P_t - R - h + y\right). \tag{8}$$

As expected, in all scenarios, the land allocated to the MV increases in the investment by the MNE, while it decreases with its price, with the degree of yield uncertainty (as measured by h) and with the revenues from the local landraces. In (7), the land allocation is not affected by the monetary benefit sharing policy, which is in our setting lump sum. Nevertheless, it is directly affected by the technology transfer magnitude as shown in (8).

Stage 1: *Bioprospecting firm's choices*

In the first stage, the MNE defines the price and R&D investment, which determines the expected quality of the MV, subject to land availability constraint and to the reaction function of the farmer under all possible scenarios. First order conditions imply that, in equilibrium, we have the results summarized in Table 1.

Free Access	Monetary Benefit Sharing	Technology Transfer
$I_f = \frac{r(1-4h)}{(2\gamma-1)c}$	$I_m = \frac{(1-4h)r}{(\beta+2\gamma-1)c}$	$I_t = \frac{r(1-4h-2\phi)}{c(2\gamma-1)}$
$P_f = \frac{r(\gamma-2h)}{(2\gamma-1)c}$	$P_m = \frac{(\gamma-2h+2h\beta)r}{(\beta+2\gamma-1)(1-\beta)c}$	$P_t = \frac{r(\gamma-2h-\phi)}{c(2\gamma-1)}$

Table 1: Price and Investment in Equilibrium

Substituing the equilibrium values for I and P under each of the three scenarios back into land allocation choosen in the second stage (from (6), (7) and (8)) respectively, we obtain:

$$L_f = \frac{4rh\,(1-2h) - c\,(R+h-y)\,(2\gamma-1) - r\gamma}{(2\gamma-1)c^2} \tag{9}$$

under free access;

$$L_m = \frac{r(4h\,(1-\beta)\,(1-2h) - \gamma) - (R+h-y)c\,(1-\beta)\,(\beta+2\gamma-1)}{c^2\,(1-\beta)\,(\beta+2\gamma-1)} \tag{10}$$

under monetary benefit sharing, and

$$L_t = \frac{c\,(y-R-h)\,(2\gamma-1) - r\left(\gamma - 4h - 2\phi + 8h\phi + 8h^2 + 2\phi^2\right)}{(2\gamma-1)\,c^2} \tag{11}$$

under the technology transfer.

Comparative statics[12] shows that a large share of benefit under monetary benefit sharing, β, leads the MNE to decrease its investments as the policy stringency makes the MNE less motivated to invest

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[12] Detailed comparative statics can be found in Appendix 2.

in the modern variety ($\frac{dI_m}{d\beta} < 0$). Also, to compensate the related loss in profits, the MNE increases the price ($\frac{dP_m}{d\beta} > 0$). Both the low quality and price increase lead to a decrease in the land allocated to MV ($\frac{dL_m}{d\beta} < 0$) by the local owner.

On the other hand, with the technology transfer the local owner benefits from a reduction in adoption costs and the MNE, anticipating the enlargement of land devoted to the MV, reacts decreasing the investment on the MV in order to reduce the genetic diversity erosion ($\frac{dIt}{d\phi} < 0$). Nevertheless, since the quality reduction causes the world demand to decrease, the MNE compensates the loss of profits decreasing the MV price ($\frac{dP_t}{d\phi} < 0$). In this case, the price effect overcomes the quality effect and the land allocated to MV increases ($\frac{dL_t}{d\phi} > 0$).

4 Policy implications

In this section we compare the equilibrium levels of investment in R&D, price and land allocation under the different scenarios, to provide some policy relevant insights.

4.1 *R&D investment*

We compare the investment in R&D on the MV under free access and each of the mechanisms in turn:

$$I_f - I_m = (1 - 2\gamma - \beta)^{-1} (2\gamma - 1)^{-1} c^{-1} (4h - 1) r\beta > 0; \tag{12}$$

$$I_f - I_t = 2 (2\gamma - 1)^{-1} c^{-1} \phi r > 0. \tag{13}$$

We therefore conclude that:

$$I_f > I_t \text{ and } I_f > I_m \tag{14}$$

As a result, and as expected, free access leads to larger R&D investments than both the monetary sharing and the technology transfer.The genetic diversity conservation policy introduction reduces MNE net marginal benefit from investments. On the other hand, comparing the R&D investments arising under the two mechanisms, we get:

$$I_m - I_t = (\beta + 2\gamma - 1)^{-1} (2\gamma - 1)^{-1} c^{-1} (4h\beta - 2\phi - \beta + 2\beta\phi + 4\gamma\phi) r. \tag{15}$$

leading us to our first Proposition.

Proposition 1 *R&D investments are larger (smaller) under monetary benefit sharing than under the technology transfer if the share of the monetary benefit is relatively small (large) and/or the magni-*

tude of the technology transfer is relatively large (small). The investment differential increases with uncertainty.

Proof. Note that (15) is positive if $\frac{4\phi\gamma-2\phi}{1-4h-2\phi} > \beta$, with $\frac{4\phi\gamma-2\phi}{1-4h-2\phi}$ increasing in ϕ, as $\frac{d\left(\frac{4\phi\gamma-2\phi}{1-4h-2\phi}\right)}{d\phi} = 2\left(1-4h\right)\frac{2\gamma-1}{\left(4h+2\phi-1\right)^2} > 0$. ■

When the share of monetary benefits is relatively small (and the technology transfer magnitude is relatively large) the marginal benefit for the MNE to increase R&D investments is large under monetary benefit sharing, and small under the technology transfer, due to the incentives related to the future bioprospecting benefits, as L_t increases with ϕ *ceteris paribus.* The opposite is true when monetary (technology transfer) benefit share in favour of the local farmer is relatively large (small).

Moreover, comparative statics shows that $\frac{dI}{dh} < 0$, i.e. a larger variability of MV productivity leads the MNE to invest less under any scenario. However, under technology transfer the MNE decreases its investment more (in absolute terms) than under monetary benefit sharing. As a result, when $I_m - I_t > 0$, the differential increases with h, while when $I_m - I_t < 0$ the opposite happens.

4.2 *Price of the modern variety*

Comparing the price for the new variety under free access with the price arising under the two benefit sharing mechanisms, we get:

$$P_f - P_m = \frac{\left(2h\left(1-\beta\right)+\gamma\left(\beta+2\gamma-2\right)\right)r\beta}{\left(\beta+2\gamma-1\right)\left(2\gamma-1\right)\left(\beta-1\right)c} < 0; \tag{16}$$

$$P_f - P_n = \left(2\gamma-1\right)^{-1}c^{-1}\phi r > 0. \tag{17}$$

It follows that:

$$P_t < P_f < P_m \tag{18}$$

Proposition 2 *A technology transfer implies a smaller MV price than under free access. Further, the latter is lower than the price resulting under monetary transfer.*

Intuitively, the monetary benefit sharing mechanism determines (as compared with the free access case) lower incentives to invest in the MV since a share β of MNE revenues must be transferred to the local farmer. To compensate the related profits loss, the MNE increases the price, and this also generates benefits in terms of future potential bio-prospecting, as the farmer reacts by decreasing land allocated to the MV (as we will show shortly). On the other hand, under the technology transfer, the land allocation impact due to lower adoption costs for the local farmer is counterbalanced by the lower investments and quality chosen by the MNE. At the same time, a low quality let the world demand decrease, but this variation is compensated by the MNE, by lowering the price of the MV.

4.3 *Land allocation and genetic diversity conservation*

Comparing land allocation decisions, we have the following result:

$$L_t - L_f = (-2)\left(2\gamma - 1\right)^{-1} c^{-2} \left(4h + \phi - 1\right) r\phi > 0. \tag{19}$$

Also, as $I_f > I_m$ and $P_f < P_m$, then it is straightforward to conclude that:

$$L_f > L_m \tag{20}$$

and consequently:

$$L_t > L_f > L_m \tag{21}$$

Proposition 3 *From the genetic diversity conservation point of view, the monetary benefit sharing mechanism is the most favorable policy instrument; under a technology transfer, the land allocated to the MV is even larger than in the free access case.*

As we discussed above, the choice of the land allocation is directly affected by both the quality and the price of the MV. Thus, given the results in (18) and (14), it is reasonable to have the lowest MV land allocation under the monetary benefit sharing mechanism as a consequence of a *price driven positive ecological feedback effect.* In other words, the MNE reacts to the introduction of a monetary benefit sharing mechanism by increasing the price of the MV, as well as by lowering its quality, and this results in larger conservation (i.e. a lower L_t).

Under a technology transfer, the investments of the MNE are lower than under free access, but this is only partially compensated by a decrease in price. As a result, we have a *quality driven negative ecological feedback effect* since the land allocated to the new variety is larger than under free access.

5 Concluding remarks

In this paper we investigate how benefit sharing mechanisms impact on both the bioprospecting R&D investments and the genetic diversity conservation. We explore this issue in a context of agricultural genetic diversity where the output of the bioprospecting activity can, *per se*, be a threat to the *in-situ* conservation.

The agricultural diversity is a domesticated biodiversity that depends on the owners' land allocation choices. The traditional varieties and their landraces, still cultivated in rare ecological niches of developing countries, are rich in genetic diversity and supply a wide range of private and public benefits. Among the latter, there is an option value linked to the genetic valuable traits that could be exploited in the future by the bioprospecting industry for producing new modern varieties that, once released in the market, can enter in land competition with the traditional varieties. A shifting of the land to the modern varieties, thus, can benefit farmers when these are highly productive and responsive but also can produce genetic erosion and reduction of the biological stock from which the bioprospecting industry can develop new varieties in the future .

This issue has been here analyzed in a framework where a bioprospecting multinational incorporates, in her objective function, the impact that the price and quality of the new modern variety has on the land allocation decisions of the genetic diversity owner, i.e. a local farmer, and consequently on the future opportunities of bioprospecting. The farmer observes price and expected quality set by the bioprospecting firm, and allocates its land between the modern variety and the local landraces. The multinational decides investments in quality and price so as to maximize the expected value of its profit balancing current revenues, linked to current demand, and future revenues that depend, instead, on the stock of genetic resources conserved *in situ*. This specific modelling strategy allows us to identify specific feedback effects that have been, to the best of our knowledge, neglected so far in the literature, although they could be expected to heavily influence the effectiveness of biodiversity policies, by generating explicit ecologic and economic trade-offs.

Our results, although remarking the potential effectiveness of benefit sharing mechanisms as instruments for biodiversity conservation, also underline that the agricultural genetic diversity stock could be undermined by an incorrect design. In fact, our setting highlights that the bioprospecting firm, anticipating the land allocation decisions of the local farmers, and accounting for the future bioprospecting profits loss, adjusts the quality and the price of its bioprospecting output to optimally react to such an expected loss. However, the overall impact on land allocation and, therefore, on conservation, depends crucially on the chosen policy. Under a monetary transfer, revenue related incentives push the bio-prospecting firm to decrease quality and increase price, implying a larger conservation. On the other hand, under a technology transfer the local farmer faces a reduction in the adoption costs of utilizing the new agricultural technology, land allocated to the modern variety increases and conservation is reduced. Our framework suggests therefore possible forces that move mechanisms based on technology transfers away from conservation, while the opposite holds with reference to monetary based mechanisms.

The results of our research should be seen as indicative of the underestimated potentially negative feedback effect of specific benefit sharing mechanisms between local farmers and bioprospecting firms in terms of genetic diversity conservation, suggesting therefore potential paths for future research.

Several conceptual caveats apply to our analysis so far: first, they are strictly related to the issue of the domesticated diversity, as it is the agricultural genetic diversity, in which there is competition between bioprospecting output and the diversity itself. Consequently, our framework is not directly applicable to other issues, such as wild genetic diversity. Second, we ignore the role of the gene banks. Although we concentrate on the *in-situ* conservation, being it the most important source of the genetic traits' evolutionary process, further research on how the banks could impact on the multinational incentives to account for the local owner land allocation should be developed. Finally, our framework could indeed be generalized, as we adopt specific functional forms and we model benefits from future bioprospecting in a simple way. The related loss of generality is however more than compensated by significant gains in the readibility of our results. At the same time, we think that the results of our theoretical exercise provide food for thought for policy makers involved in genetic conservation issues.

Appendix

Appendix 1 Parameters assumption

Free access

Second order conditions require $\gamma > \frac{1}{2}$. In order to have both positive P and I in equilibrium, we assume that $r(\gamma - 2h) > 0$, implying $h < \frac{\gamma}{2}$. Also, we need to assume that $r(1-4h) > 0$, so that we assume $h < \frac{1}{4}$.To ensure that in equilibrium $I_f - P_f > 0$, we further assume $\frac{r(1-4h)}{(2\gamma-1)c} - \frac{r(\gamma-2h)}{(2\gamma-1)c} = \frac{(2h+\gamma-1)r}{(1-2\gamma)c} > 0$, requiring $2h + \gamma - 1 < 0$.

Monetary benefit sharing

Second order conditions require $\beta + 2\gamma - 1 > 0$. In order to have $P_m > 0$ we need $\gamma - 2h + 2h\beta > 0$, that is, $\gamma > 2h\,(1-\beta)$ .Also, for $I_m > 0$ we must have $1 - 4h > 0$,so $h < \frac{1}{4}$. Positive world demand implies: $I_m - P_m = (\beta + 2\gamma - 1)^{-1} (\beta - 1)^{-1} c^{-1} (2h + \beta + \gamma - 2h\beta - 1)\, r > 0$, so that we need to assume $2h - 2h\beta + \beta + \gamma - 1 < 0$, which yields $\gamma < (1-2h)(1-\beta)$.

Combining with the second order condition, for γ we assume $(1-2h)(1-\beta) > \gamma > 2h\,(1-\beta)$.

Technology transfer

Second order conditions for a maximum require, again, $\gamma > \frac{1}{2}$, while $P_n > 0$ requires $\gamma - 2h - \phi > 0$, i.e. $\gamma > 2h + \phi$.Also, for $I_t > 0$ we must have $-4h - 2\phi = 1 - 2(2h + \phi) > 0$,so we assume that $\frac{1}{2} > 2h + \phi$. Besides, to assure that world demand is positive, we need to have: $I_n - P_n = (1 - 2\gamma)^{-1} c^{-1} (2h + \gamma + \phi - 1) r > 0$,which requires $2h + \phi + \gamma < 1$.

Turning to land allocation and farmers' revenues, to have $0 < L \leqslant 1$ and positive expected revenues under any scenario we need the following three conditions to hold:

$R + h < y \leqslant c + R + h + \frac{r\gamma - 4hr(1-2h)}{c(2\gamma-1)}$;

$R + h < y \leqslant c + R + h + \frac{r(\gamma-2h+2h\beta)}{c(1-\beta)(\beta+2\gamma-1)} - \frac{2hr(1-4h)}{c(\beta+2\gamma-1)}$;

$R + h < y \leqslant c + R + h + \frac{r\left(8h^2+8h\phi-4h+2\phi^2-2\phi+\gamma\right)}{c(2\gamma-1)}$.

As $\frac{r\gamma-4hr(1-2h)}{c(2\gamma-1)} - \frac{r\left(8h^2+8h\phi-4h+2\phi^2-2\phi+\gamma\right)}{c(2\gamma-1)} = 2r\phi\frac{1-4h-\phi}{c(2\gamma-1)} > 0$ and $\frac{r\gamma-4hr(1-2h)}{c(2\gamma-1)} - \left(\frac{r(\gamma-2h+2h\beta)}{c(1-\beta)(\beta+2\gamma-1)} - \frac{2hr(1-4h)}{c(\beta+2\gamma-1)}\right) = r\beta\frac{-4h+2\gamma+4h\beta-2\gamma^2-\beta\gamma-8h^2\beta+8h^2}{c(2\gamma-1)(1-\beta)(\beta+2\gamma-1)} > 0$, we only need to assume that:

$R + h < y \leqslant c + R + h + \min\left\{\frac{r(\gamma-2h+2h\beta)}{c(1-\beta)(\beta+2\gamma-1)} - \frac{2hr(1-4h)}{c(\beta+2\gamma-1)}; \frac{r\left(8h^2+8h\phi-4h+2\phi^2-2\phi+\gamma\right)}{c(2\gamma-1)}\right\}$.

Appendix 2 Results from Comparative statics

	$d\beta$	$d\phi$
dP_m	$\frac{2r\left(h\beta^2+\beta\gamma-2h\beta+\gamma^2-\gamma+h\right)}{c(\beta-1)^2(\beta+2\gamma-1)^2} > 0$	
dI_m	$\frac{(4h-1)r}{c(\beta+2\gamma-1)^2} < 0$	
dL_m	$\frac{2h}{c}\frac{dI_m}{d\beta} - \frac{1}{c}\frac{dP_m}{d\beta} < 0$	
dP_t		$\frac{r}{c-2c\gamma} < 0$
dIt		$\frac{2r}{c-2c\gamma} < 0$
dL_t		$\frac{2r(1-2\phi-4h)}{(2\gamma-1)c^2} > 0$

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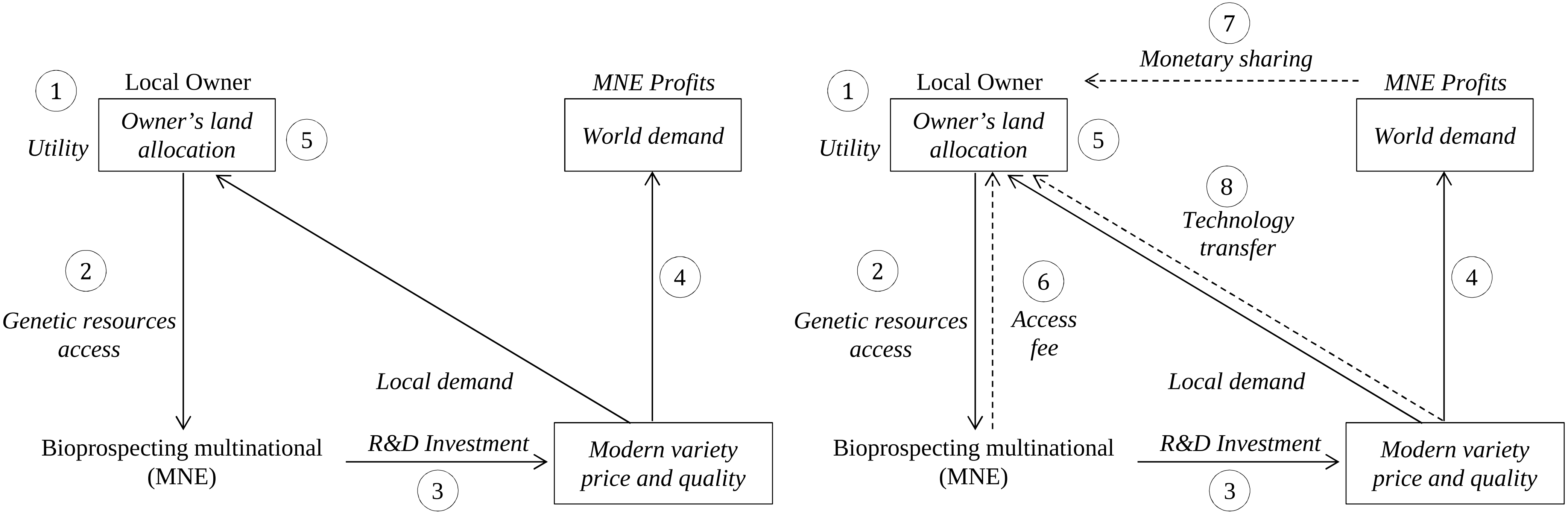

a) Free access **b) Benefit sharing mechanisms**

Figure 1. Conceptual Framework