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How much is too much? Individual biodiversity conservation

Mintewab Bezabih Ayele
Environment and Climate Research center, Ethiopian Development Research Institute

Jesper Stage
Luleå University of Technology

Abstract

The individual farmer has little incentive to care about the public good properties of on-farm biodiversity in the form of different crop varieties. There is a common assumption that, because of this, farmers will tend to maintain too little biodiversity on their farms compared with the social optimum. However, in developing countries, this assumption does not fit with the empirical data: because of poorly functioning insurance markets, farmers tend to maintain a wide range of different crop varieties to hedge against weather shocks and other uncertainties. In this paper we develop a theoretical model to account for this apparent contradiction, and show that farmers may in fact even maintain too much biodiversity on their farms, compared with the social optimum.

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Contact: Mintewab Bezabih Ayele - MintewabAyele@gmail.com, Jesper Stage - Jesper.Stage@ltu.se.

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1. Introduction

This paper aims to assess the nature of private and public benefits from conserving biodiversity in agricultural settings where private and social agents consider different factors in the decision to conserve biodiversity. We show that a common assumption – i.e. that private agents will underinvest in biodiversity compared with socially optimal levels of such investment – may not actually hold. Our theoretical model reveals that, in fact, private agents may actually maintain greater agricultural biodiversity than a social planner would.

The crop choice decisions made by a farmer reflect the individual's objective of utility maximisation. Clearly, such choices also determine whether or not desirable genetic resources continue to be grown in situ. Conserving crop genetic materials in-situ rather than ex-situ allows such materials to be maintained in their natural environment, where they can interact with their natural competitors such as pests, predators and pathogens, and evolve into even more desirable resources (Demissie and Tanto 2002; Lewis and Mulvany 1997). Crop genetic materials are not necessarily lost permanently even if they cease to be grown in situ in a specific region, as they may be maintained in situ in other regions and ex situ in seed banks. Nonetheless, continuing to grow crop varieties in a region where they have traditionally been grown may have a social value above that which the individual farmer attaches to them. Given all of the above, understanding why a private individual would choose to conserve biodiversity is critical in designing appropriate conservation instruments, especially in the context of the social value of maintaining diverse genetic materials in situ. The objective of this paper, therefore, is to assess possible synergies and divergences in the private and public valuations of biodiversity.

The popular perception is that individual farmers may underinvest in biodiversity because they do not benefit fully from it. Furthermore, it is also popularly alleged that, when individual farmers make choices that are optimal for them in response to global trends, such choices cause levels of crop biodiversity to fall below a socially optimal threshold (Van Dusen *et al*. 2007). In this respect, Harlan (1972) and Frankel (1970) warned against the extensive displacement of landraces which they had observed during the early years of the Green Revolution, particularly in the more favourable agronomic environments where high-yielding crop varieties were adopted first.

On the other hand, several studies indicate that small farmlands are still huge reservoirs of genetic materials. For instance, farmers in Nepal maintain an estimated 2,000 rice landraces in association with their wild and weedy relatives (Upadhyay and Gupta 2000), and about 127 varieties of seven crops are maintained by just 380 households in a village in Ethiopia (Bezabih 2007). Brush (2004) has cautioned that genetic erosion is not as broad a phenomenon as is normally believed, and that the presumption of such erosion is a testable hypothesis worthy of study in order to assess the optimal level of biodiversity.

Thus, while there could be valid concerns about the erosion of agrobiodiversity, it is clear that agrobiodiversity is being maintained in many locations, and one needs a proper assessment of what motivates farmers who appear to maintain high levels of such diversity in their crops.

2. The benefits of biodiversity

2.1 Providing genetic materials for plant breeding

A rich and varied source of genetic materials enables improved varieties of plants to be developed because it serves as essential input in the process of agricultural innovation. Such innovation is enhanced in turn by technological innovation, which raises the level of agricultural production above a previous one. The resulting expansion in production possibilities leads to a high net present value of future benefit flows (Aghion and Howitt 1992).

2.2 Coping with market imperfections and imperfect substitutability

In a situation where markets work perfectly, production decisions are based solely on input and output price considerations, and farm household consumption decisions are recursive to production decisions. With imperfect markets, however, there is an imperfect substitution between market and home production, and recursive consumption decisions do not hold. Instead, the production and consumption decisions are made simultaneously and, hence, there is non-separability in production and consumption (De Janvry *et al*. 1991).

Indeed, output market integration is critical to the household's decision as to which landrace to plant. For example, Van Dusen *et al*. (2007) and Bezabih and Gaeback (2010) find that distance from a major road – which is used as a proxy for market availability – is critical in determining not only which landrace is planted, but also the level of crop diversity involved. This could be because households will be forced to produce goods they demand but which the market does not supply. Also, some local crop varieties might have consumption qualities favoured by certain localities, but they may not be widely produced. Moreover, these local varieties may have limited availability in the market, which would also prompt own production (Smale 1995).

2.3 Coping with missing insurance markets

Another reason why individual households may regard a diversified crop portfolio as beneficial to them relates to weather risk in production. The magnitude of weather risk in many low-income, rain-fed farming areas is striking, and the coefficient variation of farm profits is estimated as being up to 125% (Rosenzweig and Binswanger 1993). Although households could be shielded from such weather risks by well-functioning insurance markets, in low-income smallholder settings such markets are generally missing or imperfect. Farmers therefore adjust their farming practices as a buffer to these risks (Carter 1997). For example, a household may align its crop portfolio choice with expected changes in the weather. A case in point is reported by Di Falco and Chavas (2006), who show that high levels of crop diversity can reduce a farmer's exposure to the downside risk of crop failure.

3. The model

Our main premise for the model is that individual households may not have the incentive to invest in biodiversity for future agricultural innovation such as plant breeding, and that they may not consider the loss of genetic materials that insure against covariate risks as a cost. From society's point of view, therefore, farms may underinvest in the conservation of biodiversity.

On the other hand, on-farm biodiversity may have an insurance value to farm households that operate in uncertain production environments where insurance markets are absent. In addition, imperfect output markets may encourage diversification due to imperfect substitutability between home production and the market, and non-separability in production and consumption decisions.

Consider a farming region with N different farm households, each of which faces weather risk which is at least partly idiosyncratic to the individual farm, and where different households may have farms of different size and quality. Farm household i generates a yield from agricultural production $g_i(\mathbf{x}_i, b_i, \mathbf{v}_i)$, determined by its choice of non-biodiversity inputs $\mathbf{x}_i$, its choice of crop diversity b_i, and local weather $\mathbf{v}_i$; weather is assumed to be a normally distributed random variable. Assume that $g_i(\mathbf{x}_i, b_i, \mathbf{v}_i)$ can be approximated by $g_i(\mathbf{x}_i, b_i, \mathbf{v}_i) \approx f_1(\mathbf{x}_i, b_i) + f_2(\mathbf{x}_i, b_i)^{1/2} e_1(\mathbf{v}_i)$, where f_1 denotes the expected yield and e_1 is normalised ($E(e_1(\mathbf{v}_i)) = 0$, $E(e_1(\mathbf{v}_i)^2) = 1$), such that f_2 denotes the variance of the yield.

Biodiversity b_i on an individual household's farm contributes to the overall biodiversity B available to it as well as to other households' farms. Different farmers may have partly or wholly overlapping choices of crop diversity, such that $b_i \leq B \leq \sum_N b_i$ and $0 < \frac{\partial B}{\partial b_i} \leq 1$. Each crop variety (and the future benefits from it) is assumed to be available to all farm households in the region, provided that it is maintained on at least one farm in the region. Where there is only one farm household growing a specific variety, abandoning it will permanently reduce the crop diversity available in the region. (As noted earlier, one could reintroduce the variety in future by using seeds from other regions or from seed banks, but this is usually far costlier than maintaining it in the region, and so individual farmers are unlikely to reintroduce it.) If the household is one of only a few growing a specific variety, abandoning it also entails risking a loss of available crop diversity in the future. Thus, the household's planting decisions do potentially – albeit only slightly – affect the future availability of crops in the region. However, unless the household is the only remaining household still growing a specific variety, the relationship between b_i and B will not be one-to-one.

From the perspective of the individual farm household, b_i is a private good which matters because of the issues raised in sections 2.2 and 2.3 above (i.e. through its effects on the household's own, current, production) while B is a public good which matters because of the issues raised in section 2.1 (i.e. through its effects on future opportunities). Thus, while the farm household primarily sees b_i as a private good, its decisions about b_i will contribute to the overall availability of the public good, B.

We assume that the planting decisions made by the household in a specific period do not affect what decisions it will make in future periods unless such decisions reduce the biodiversity available to farmers in the region in future. Thus, we can largely ignore future planting decisions in our optimisation problem, other than noting that the survival of a specific crop or crop variety (at least on some farm in the region) affects the utility in each period. The alternative, modelling this as an infinite-horizon problem, makes the analytics far more unwieldy and provides no qualitatively new insights. For simplicity, therefore, we focus only on how the decisions made in the period being studied affect the harvest in that period and the biodiversity available in the next period.

Thus, the household's instantaneous utility from a specific period can be denoted by $U(g_i(\mathbf{x}_i, b_i, \mathbf{v}_i)) + \delta_i A(B)$, where U is the household's utility of consumption during that period, $\delta_i A(B)$ is the 'availability value' that the household attaches to knowing that the overall biodiversity B in the region is available to it for the next period's planting decisions, and δ_i denotes the household's discount factor. For the sake of simplicity, we assume that the two different utility terms are separable. We have $\frac{\partial U}{\partial g_i} > 0, \frac{\partial^2 U}{\partial g_i^2} < 0, \frac{\partial A}{\partial B} > 0, \frac{\partial^2 A}{\partial B^2} < 0,$ and $A << U$. The last inequality reflects that, while the individual household does attach a value to biodiversity and the potential future benefits linked to it, that value is – in line with the public debate on this issue – assumed to be very low compared with the value attached to the benefits of consumption.

Under uncertainty, we assume that $U(g_i)$ is a Von Neumann–Morgenstern utility function representing the preferences of the farmer. Following Pratt (1964),[1] the equivalent consumption utility function can be written as follows:

$$E(U(g_i)) = U(E(g_i) - R) \approx U(f_1(\mathbf{x}_i, b_i) - \frac{1}{2} r_i f_2(\mathbf{x}_i, b_i)) \tag{1}$$

Here, the Von Neumann–Morgenstern utility function is first transformed into the utility of expected yield and a risk premium, R, and then into a form where utility depends on expected yield, f_1, the individual farm household's absolute risk aversion, r_i, and the variance of the yield, f_2. The advantage of this decomposition of the utility function is that it enables us to assess the role of diversity in reducing(/increasing) variance in production uncertainty.

We assume that monocropping or growing a very limited number of crops and crop varieties gives the maximum expected yield. The impact of increased biodiversity, thus, is to reduce expected productivity (Norberg *et al*. 2001). On the other hand, Di Falco and Chavas (2006) find that diversity tends to decrease the variance in crop production, and Tilman *et al*. (2005) similarly show that diversity enhances the temporal stability of production. Thus, we have $\frac{\partial f_1}{\partial b_i} < 0, \frac{\partial^2 f_1}{\partial b_i^2} < 0, \frac{\partial f_2}{\partial b_i} < 0$, where the magnitude of $\frac{\partial f_2}{\partial b_i}$ will depend on the degree to which weather risks are correlated between the different crop varieties that the household grows. The household's first-order condition with respect to biodiversity b_i is then given by –

$$U'(...)\left(\frac{\partial f_1}{\partial b_i} - \frac{1}{2} r_i \frac{\partial f_2}{\partial b_i}\right) + \delta_i \frac{\partial A}{\partial b_i} = 0 \tag{2}$$

[1] See the Appendix for a full derivation.

$$\Rightarrow \frac{\partial f_1}{\partial b_i} = \frac{1}{2} r_i \frac{\partial f_2}{\partial b_i} - \delta_i \frac{1}{U'} \frac{\partial A}{\partial b_i} \tag{3}$$

For the three terms in Equation (3), we have $\frac{\partial f_1}{\partial b_i} < 0, \frac{1}{2} r_i \frac{\partial f_2}{\partial b_i} < 0,$ and $-\delta_i \frac{1}{U'} \frac{\partial A}{\partial b_i} < 0$. The larger the absolute magnitude of $\frac{\partial f_1}{\partial b_i}$, the greater the on-farm biodiversity.

Let us now consider the decision problem of a social planner wishing to maximise welfare for the *N* farm households in the region, as follows:

$$\sum_i^N \left[E(U(g_i)) + \delta_s A(B) \right] = \sum_i^N \left[U(f_1 - \frac{1}{2} r_s f_2) + \delta_s A(B) \right] \tag{4}$$

A few key differences between the individual farmer's and the social planner's decision problems are immediate: For one, the social planner will have lower (or zero) risk aversion r_s than the farmer does (Arrow and Lind 1970), because of a greater capacity to pool risk. The social planner is also likely to have a higher discount factor δ_s than the individual farmer. The social planner can pool capital at the regional level, unlike the individual farmer, who can only pool capital at the farm level (ibid.), and the social planner also has lower exposure to the credit market imperfections that individual farmers (see e.g. Pender 1996; Andersson *et al*. 2011).

Finally, the social planner also takes into account the fact that decisions affecting the biodiversity on one farm will affect the availability value accruing to all farm households in the region. Thus, the first-order condition for the social planner with respect to biodiversity b_i on farm *i* becomes –

$$U'(...) \left(\frac{\partial f_1}{\partial b_i} - \frac{1}{2} r_s \frac{\partial f_2}{\partial b_i} \right) + \delta_s \sum^N \frac{\partial A}{\partial b_i} = 0 \tag{5}$$

$$\Rightarrow \frac{\partial f_1}{\partial b_i} = \frac{1}{2} r_s \frac{\partial f_2}{\partial b_i} - \delta_s \frac{1}{U'} \sum^N \frac{\partial A}{\partial b_i} \tag{6}$$

The absolute value of the first term on the right-hand side of Equation (6) is smaller than its counterpart in Equation (3), while the second term is larger.

If one compares Equation (6) and Equation (3), two important differences immediately become clear. Firstly, as a tool for risk management, farm-level biodiversity is less important to a social planner than it is to the individual farmer. The social planner's lower risk aversion implies that the benefits of reduced variance stemming from farm-level biodiversity on an individual farm are smaller from the social planner's perspective than they are from the farmer's. This means that the farmer will tend to overinvest in farm-level biodiversity b_i as a risk management tool compared with the social planner's optimum.

The second important difference, acting in the opposite direction, is that the availability value of overall biodiversity *B* becomes more important to the social planner – relative to the objectives of profit and risk reduction – than it is to the individual farmer. Since each individual farmer's biodiversity decisions on his/her farm will determine the overall availability of biodiversity in the region as a whole, this means that farmers will tend to underinvest in farm-level biodiversity as a contributor to the public good B.

Thus, we have two counteracting effects: the *risk management effect* (where farm households treat on-farm biodiversity as a private good) means that farmers will tend to overinvest in biodiversity, while the *public good effect* linked to availability values means that farmers will tend to underinvest in it. One cannot determine on theoretical grounds which of these effects will dominate: this is an empirical matter in the farming region concerned. However, the reasoning above suggests that if each farm household provides the privately optimal biodiversity on its own farm, the aggregate outcome may actually be that the farm households in the region as a whole provide too much of the public good.

4. Conclusions

The simple model set up in this paper demonstrates that the intuitive expectation that farmers will invest too little in maintaining agrobiodiversity on their land may not necessarily hold, given the market context facing farmers in many developing countries. Ordinarily, farm households would tend to provide too little of the public good (overall agrobiodiversity in the region) voluntarily, for much the same reasons that private provision of public goods is frequently suboptimal. However, the private good aspects (of agrobiodiversity on the household's own farm) are sufficiently valuable that, if their risk aversion is sufficiently high, farmers may actually maintain too much agrobiodiversity on their land relative to the socially optimal level.

An additional point can be made. If biodiversity is valued as a public good for its availability values linked to future crop breeding opportunities, farmers with high discount factors will tend to have more crop biodiversity on their farms than those with low discount factors will. However, the effect of differences in discount factors effect is likely to be swamped by the more powerful effect of differences in risk aversion; regardless of discount factor, farmers with high risk aversion can be expected to have more on-farm biodiversity than those with low risk aversion.

A final implication of our results is that policy measures intended to improve farmers' welfare may have unintended effects on the maintenance of agrobiodiversity. For example, improved access to credit would increase farmers' subjective discount factors, and one intended effect should thus be to increase on-site biodiversity. However, measures that reduce farmers' exposure to risk – which would include improved access to credit, improved access to insurance, and numerous other potential policy interventions – would reduce farmers' risk aversion and could, thus, lead to lower agrobiodiversity. If private agrobiodiversity is initially too high in relation to the social optimum, this reduction in agrobiodiversity would be a good thing. However, if policy measures continue to improve farmers' welfare and reduce their risk exposure, at some point the privately held biodiversity would become less than socially optimal. Ironically, causing the individual farmer's valuation of risk to converge with the social planner's could simultaneously cause farmers' behaviour overall to diverge from the social optimum. Thus, relative to the socially optimal levels, both the initial level of privately held agricultural biodiversity and the change in private biodiversity when policies are introduced to improve farmers' welfare need to be carefully assessed.

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Appendix: Derivation of Equation (1)

Following Pratt (1964), let us define the risk premium R as the certain cost for which $E(U(g_i)) = U(E(g_i) - R)$. Ignoring higher-order terms and Taylor-expanding gives us $E(U(g_i)) = U(E(g_i) - R) = U(f_1(\mathbf{x}_i, b_i) - R) \approx U(f_1(\mathbf{x}_i, b_i)) - RU'(f_1(\mathbf{x}_i, b_i))$.

However, we also have $E(U(g_i)) = E(U(g_i(\mathbf{x}_i, b_i, \mathbf{v}_i))) \approx E(U(f_1(\mathbf{x}_i, b_i) + f_2(\mathbf{x}_i, b_i)^{1/2} e_1(\mathbf{v}_i)))$, and Taylor-expanding this expression (again ignoring higher-order terms) gives us $E(U(g_i)) = U(f_1(\mathbf{x}_i, b_i)) + \frac{1}{2} f_2(\mathbf{x}_i, b_i) U''(f_1(\mathbf{x}_i, b_i))$.

Setting the two Taylor expansions equal, we have

$$-RU'(f_1(\mathbf{x}_i, b_i)) \approx \frac{1}{2} f_2(\mathbf{x}_i, b_i) U''(f_1(\mathbf{x}_i, b_i)) \Rightarrow R = -\frac{1}{2} f_2(\mathbf{x}_i, b_i) \frac{U''(f_1(\mathbf{x}_i, b_i))}{U'(f_1(\mathbf{x}_i, b_i))} = \frac{1}{2} f_2(\mathbf{x}_i, b_i) r_i$$

where the rightmost expression defines the farmer's absolute risk aversion, r_i.