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The economics of agrobiodiversity conservation for food security under climate change

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ABSTRACT: Subsistence-based and natural resource-dependent societies are especially vulnerable to climate change. In such contexts, food security needs to be strengthened by investing in the adaptability of food systems. This paper looks into the role of agrobiodiversity conservation for food security in the face of climate change. It identifies agrobiodiversity as a key public good that delivers necessary services for human wellbeing. We argue that the public values provided by agrobiodiversity conservation need to be demonstrated and captured. We offer an economic perspective of this challenge and highlight ways of capturing at least a subset of the public values of agrobiodiversity to help adapt to and reduce the vulnerability of subsistence based economies to climate change.

KEYWORDS: Climate change, adaptation, agrobiodiversity, economic incentives, resilience.

JEL classification: Q18, Q24, Q54.

La economía de la conservación de la agrobiodiversidad para la seguridad alimentaria ante el cambio climático

RESUMEN: Las sociedades dependientes de recursos naturales de subsistencia son especialmente vulnerables al cambio climático. En este contexto, la seguridad alimentaria debe de fortalecerse mediante la inversión en la adaptabilidad de los sistemas alimentarios. Este artículo se enfoca en el papel de la conservación de la agrobiodiversidad para la seguridad alimentaria ante el cambio climático y trata la agrobiodiversidad como un bien público que genera servicios básicos para el bienestar humano. Una vez que los valores públicos de la conservación de la agrobiodiversidad son puestos en relieve, éstos deben de ser puestos en valor. Aquí ofrecemos una perspectiva económica de este reto y subrayamos formas para la captura de varios valores públicos de la agrobiodiversidad para la adaptación al cambio climático.

PALABRAS CLAVES: Cambio climático, adaptación, agrobiodiversidad, incentives económicos, resiliencia.

Clasificación JEL: Q18, Q24, Q54.

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1. Introduction

Climate change involves long-term changes in mean temperature and/or rainfall patterns and increased climate variability, reflected by an increasing occurrence of severe climate events such as droughts and floods (Smit and Skinner, 2002; IPCC, 2007). Poor, mainly subsistence-based and natural resource-dependent societies in developing countries are especially vulnerable to climate change. They are sensitive and exposed to natural hazards, and the severity and higher frequency of such hazards undermines the asset portfolio needed to adequately cope and to adjust to them (Ribot *et al.*, 2009; UNDP, 2007). For the millions of small farmers in developing countries already struggling to eke out vulnerable livelihoods, one dire consequence is an increase in food insecurity. This is a particular risk in regions where climate acts both as an underlying chronic issue and a short-lived shock, as poor farmers often have a low ability to cope with shocks and to mitigate long-term stresses (Bohle *et al.*, 1994; Dilley and Boudreau 2001; Gregory *et al.*, 2005; Challinor *et al.*, 2007). Although it is also true that they have impressive and widely documented coping abilities, these are expected to be challenged by the scope and speed of future climate change (Challinor *et al.*, 2007).

Household-level food insecurity is due to seven main drivers: those that act by reducing food production (poverty, lack of education, unavailability of employment, failures in property rights), those that act by restricting access to food (food price increases), and those that act via both channels (poor market access and climate/environmental change) (Scholes and Biggs, 2004). In contexts where these drivers play a key role, such as Sub-Saharan Africa, climate change will further stress already vulnerable livelihoods, making it difficult to reach the United Nations Millennium Development Goals adopted in 2000, especially with regard to halving the proportion of people who suffer from hunger by 2015 (Rosegrant and Cline, 2003). Hence, development agencies need to facilitate the adaptation of agricultural systems by improving the adaptability of food systems in the face of climate change. This will decrease the vulnerabilities of the poor and enhance their food security (Mortimer and Adams, 2001; Smit and Skinner 2002; Howden *et al.*, 2007; Lobell *et al.*, 2009). This also implies investing in adaptive processes that secure food availability (production, distribution and exchange) as well as food access (affordability, allocation and preference) and food utilization (nutritional and societal values and safety).

The largest investments in food production continue to be associated with agricultural innovations, which are often advocated as crucial for agricultural climate change adaptation (e.g., Ainsworth *et al.*, 2008). These initiatives, predominantly breeding programs to increase the productivity of some major crops and livestock, are increasingly in the hands of fewer private biotechnology and agribusiness actors (Byerlee and Fisher, 2002). Much less emphasis is being put on local systems that rely on existing natural, human and social assets such as biodiversity, traditional knowledge and social capital underpinning collective action to ensure food security (Thrupp, 2000; Esquinas-Alcázar, 2005; Scherr and McNeely, 2008; Jackson *et al.*, 2010; Brussard *et al.*, 2010).

Agrobiodiversity can be understood as the diversity within and among species found in an agro-ecosystem that contribute to food and agriculture, including planned (domesticated) biodiversity (i.e., the diversity of crops and livestock genetic resources), as well as all other plant and animal genetic resources (i.e. crop wild relatives) (Perrings *et al.,* 2006; Jackson *et al.*, 2007; Smale and Drucker, 2008). Here we refer to agrobiodiversity as the diversity of plant and animal genetic resources (PAGR) relevant for food and agriculture.

Agrobiodiversity and climate change interact in two ways. Agrobiodiversity is threatened by climate change as rapid shifts in local environmental conditions may drive species to extinction, yet it also represents a crucial resource for adaptation to climate change. This paper addresses the second interaction, namely the potential role of agrobiodiversity conservation for food security in the face of climate change. It addresses the role of agrobiodiversity from an economic perspective and points out alternative ways through which economic instruments could be used to secure the insurance and option values of agrobiodiversity.

The next section introduces the concept of the value of agrobiodiversity associated with the concepts of adaptation, resilience, 'sustainagility' and food security in the context of climate change. Then section 3 discusses the reasons behind the loss of agrobiodiversity from an economic perspective. Section 4 looks into the policy toolbox to address the problem of the socially suboptimal investment level in agrobiodiversity conservation and section 5 concludes the paper pointing at the need for new research on the interface between food security, agrobiodiversity conservation and climate change adaptation.

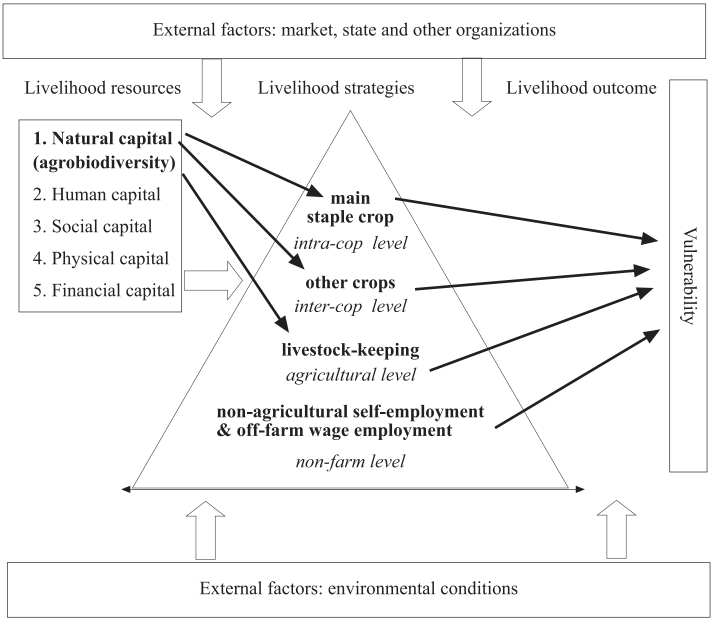
2. The value of agrobiodiversity for food security

2.1. A conceptual framework

There is an *external* angle to livelihood vulnerability, i.e. the exposure of the livelihood system to shifts in external shocks such as those arising from climate change, and an *internal* one, i.e. the ability of a livelihood system to respond to such situations without a reduction in well-being (Adger, 2006; Chambers, 2006). According to Scoones (1998) a livelihood system is built upon different productive livelihood resources or *assets* (natural, human, social, physical and financial capital) that enable people to engage in different livelihood *strategies,* which in turn determine livelihood *outcomes,* such as the degree of vulnerability to climatic shocks. Figure 1 illustrates the idea of a livelihood system interacting with a climatic environment and with other external factors such as institutions and organisations.

FIGURE 1

Livelihood Portfolios and Vulnerability to Climatic Risks



Source: Adapted from Scoones (1998).

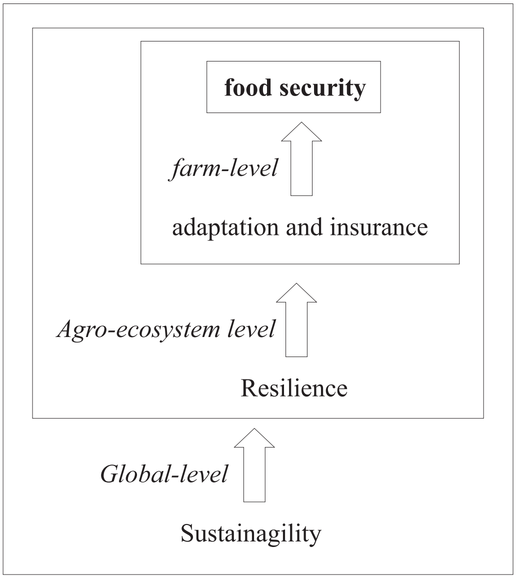
Within an agro-ecosystem, farm households' livelihood portfolios generally comprise four levels from which their optimal livelihood strategies are determined: i) the main staple crop production system (intra-crop level), ii) cultivation of other crops (inter-crop level), iii) holding of livestock (agricultural level), and iv) other forms of employment (e.g., agricultural self-employment on the home farm, non-agricultural and agricultural wage-employment off-farm) (non-farm level). The degree of sectoral and spatial diversification increases from the intra-crop level to the non-farm level. Often driven by the needs for risk mitigation and shock coping, households determine a livelihood portfolio by adopting strategies of diversification not only *across* but also *within* these four livelihood components (Ellis, 1998, 2000).

There is ample evidence that non-farm income-generating activities play an important role in compensating for income losses in times of shocks (Reardon *et al.*, 1992; Reardon and Taylor, 1996; Kijima *et al.*, 2006). There is also increasing evidence that agrobiodiversity facilitates small-scale subsistence farmers' livelihood diversification strategies (Smale, 2006; Kontoleon *et al.*, 2009). It has been widely shown that farmers tend to choose a portfolio of crop varieties and livestock breeds based on their specific traits and attributes to fulfill a wide range of production and consumption needs (Brush and Meng, 1998; Smale *et al.*, 2001; IPAGRI, 2002; Anderson, 2003; van Dusen and Taylor, 2005; Gruère *et al.*, 2009; Zander and Drucker, 2008). Farmers also shift their level of agrobiodiversity to better adapt to changing market conditions, fluctuating consumer preferences and different environmental conditions (e.g., pests and droughts). Farmers thus conserve agrobiodiversity for both cultural and economic reasons in order to spread the risk of market-driven fluctuations and climatic variability (Lipper and Cooper, 2009). It follows that agrobiodiversity can thus be regarded as *natural insurance* for farm households in social-ecologically risky environments, especially when a formal insurance market is non-existent or largely imperfect (Baumgärtner and Quaas, 2009, 2010). This insurance will become more valuable as climate change increases the risks posed by weather-related shocks.

The benefits or conservation services accruing to society from agrobiodiversity conservation (henceforth 'agrobiodiversity conservation services' or ACS) can broadly be classified at the *global* (society at large, including future generations), *agro-ecosystem* (regional and local farming community) and *farm (household)* levels (Lipper and Cooper, 2009). At all these scales, agrobiodiversity conservation can provide natural *adaptation* and *insurance* to farm households as well as *resilience* to farming communities and *sustainagility,* a newly coined term that stresses the importance of developing strategies to enhance the ability (agility) of social-ecological systems to adapt and transform taking into account tradeoffs at multiple scales (Jackson *et al.*, 2010), for instance when confronting climate change. Figure 2 shows the nested ACS in the face of climate change.

FIGURE 2

Agrobiodiversity conservation services for food security in times of climate change across spatial scales



2.2. Agrobiodiversity for adaptation and as natural insurance

Under marginal production conditions in low-intensity agro-ecosystems, local breeds and crop varieties tend to be adapted to a range of environments through a process of human selection based on farmers' preferences and traditional knowledge (Bellon, 2006; Mekbib, 2006; Ceccarelli *et al.*, 2007; Jarvis, 2007; Cavatassi *et al.*, 2011). Such environmental adaptation may take different forms contributing to agricultural productivity under climate change (Lipper and Cooper, 2009). For instance, under climate change drought resistant crop varieties may be well adapted to specific conditions of persistent droughts, while fast-maturing varieties may be better able to respond to punctual stresses such as rain shortfalls at a specific point in time (Cavatassi *et al.*, 2011). Additionally, crop varieties with biological functions that are very sensitive to the duration of light may also be better adapted to climatic variability (Niangado, 2001; Traore *et al.*, 2007).

Based on particular traits associated with adaptation functions, an on-farm portfolio of diverse PAGR can contribute to decreasing the variability and skewness of yields under changing environmental conditions, such as droughts or floods (Smale *et al.*, 1998; Di Falco and Chavas 2006, 2008; Di Falco *et al.*, 2010). Since generally farmers tend to be risk-averse, agrobiodiversity conservation, despite perhaps reducing mean yields, is a rational way to spread the risk of agricultural production shocks due to weather variability. This yield gap can be understood as the insurance risk premium that farmers are willing to pay to reduce their exposure to downside risks from climatic shocks (Baumgärtner and Quaas, 2009, 2010).

2.3. Agro-ecosystem-level resilience

The insurance value of agrobiodiversity at the farm level is also related to its contribution to agro-ecosystem resilience at a larger scale, e.g., landscale and regional scales. Ecosystems are able to cope with disturbances, but above certain thresholds natural systems may shift into another stable yet perhaps undesirable state (Scheffer *et al.*, 2001, Jackson *et al.*, 2010). A resilient ecosystem is generally more resistant and robust to shocks, avoiding or weathering them without losing its functions due to its capacity to absorb disturbances and to reorganize and renew (Carpenter *et al.*, 2001; Walker *et al.*, 2002; Folke, 2006).

PAGR interact with other biodiversity components at the landscape level. Genetic diversity is associated with the increase of supporting (e.g., soil formation, nutrient recycling...) and regulating (pollination, pest and disease management, carbon sequestration) services (Heisey *et al.*, 1997; Swift *et al.*, 2004; Hajjar *et al.*, 2008). Although empirical evidence is still relatively scant, more diverse landscapes are thought to be associated with better ecosystem functioning and greater resilience (Chapin *et al.*, 2000; Folke *et al.*, 2004; Tscharntke *et al.*, 2005), thereby increasing the sustainability of the agro-ecosystem under global perturbations (Perrings, 1998; Mäler, 2008). The underlying process is that locally redundant genotypes or crop/

plant species may take on important functions in other communities or following environmental fluctuations, thereby increasing the stability of agro-ecosystems across time and scale (Loreau *et al.*, 2003; Tascharntke *et al.*, 2005). A number of recent studies find that more diverse agro-ecosystems can be associated with higher (average) productivity in the longer term due to increased temporal stability (Schläpfer, 2002; Tilman *et al.*, 2005; Omer *et al.*, 2007).

On-farm and landscape-scale PAGR also undergo evolutionary processes, whereby genes flow between different populations and genetic resources adapt to changing conditions (Brush, 1989; Perales *et al.*, 2003). Genetic diversity may primarily contribute to ecosystem services by facilitating evolutionary processes in the field that bring forward better-adapted breeds and varieties (Faith *et al.*, 2010). Thus, more agro-diverse systems may be better able to reorganize in face of climatic shifts.

2.4. Global agrobiodiversity for sustainagility

In contrast to the concept of resilience that describes the persistence of a current system and its ability to return to its baseline function, the term *sustainagility* refers to, the properties and assets of a system that sustain the ability (agility) of agents to adapt and meet their needs in new ways“ (Jackson *et al.*, 2010:80). Sustainagility contrasts with the standard idea of sustainability as the latter tends to favour persistence (rather than transformation) of social-ecological systems along their current trajectories and the resilience to return to current baselines. In times of rapid change and increasing uncertainty, the adaptability of a system plays a major role (Holling, 2001). For example, above certain tipping points farmers may have to significantly change their farming systems by switching to new crop species/varieties or livestock breeds that are better adapted to the new conditions. Agrobiodiversity can thus be seen as a crucial asset to keep multiple options open, sustaining the ability to rapidly adapt and transform farming systems under unpredictable future conditions (Jackson *et al.*, 2010).

PAGR are the main input in crop and livestock breeding and seed improvement for industrial as well as subsistence-based farming (Dudnik *et al.*, 2001; Smale and Day-Rubenstein, 2002). It is often overlooked, though, that only the conservation of a broad range of PAGR will allow full exploration of these new technological opportunities (Hoissington, 1999; Thrupp, 2000). For instance, building upon on-farm (or *in-situ*) agrobiodiversity conservation, science may facilitate the breeding of higher yielding or more resistant animal breeding or planting material (Esquinas-Alcázar 2005; Bellon 2006; Tester and Langridge, 2010), thereby potentially contributing to greater food security (Serageldin, 1999).

Currently neglected crop varieties with seemingly unimportant traits or wild relatives with seemingly undesirable characteristics may be important for future crop improvement once new technologies become available (Esquinas-Alcázar, 2005; Bellon, 2009). This reflects the option and quasi-option value of agrobiodiversity (Pascual and Perrings, 2007). Similarly, access to a diverse resource pool and to a broad agricultural knowledge through the maintenance of agrobiodiversity may provide commercial breeders and traditional farmers with the material to develop new crop varieties that are better adapted to future challenges, such as new disease and pest epidemics that could emerge under future climate change scenarios (Bellon, 2006). In a complex world of uncertainty and increasing probability of sudden, unexpected, economic and environmental changes, the possible inter-generational benefits of safeguarding agrobiodiversity, and thus the associated option values, may be extremely high (Perrrings, 1998; Bellon, 2009).

3. Agrobiodiversity loss: an economic explanation

Despite these significant values associated with agrobiodiversity, many PAGR are currently under increasing threat and many more have already disappeared from farming systems around the world (FAO, 2007a, 2009). Furthermore, as a direct result of growing commercialization and industrialization of farming systems (e.g., via the 'Green Revolution') agro-ecosystems are increasingly characterized by high levels of intensification with low levels of agrobiodiversity (Thrupp, 2000; Drucker *et al.*, 2005; Jackson *et al.*, 2007).

Since the beginning of agriculture 12,000 years ago agrobiodiversity has been evolving through a process of human and natural selection, so that a grand variety of animal breeds and plant varieties exist within livestock and crop species. It is estimated that humans have made use of about 7,000 plant species (FAO, 1997). According to a comprehensive FAO assessment of the state of the world's animal and plant genetic resources published in 2007 and 2009, out of 7,600 livestock breeds, 20% are classified as being at risk and 9% are already extinct. Most of these are located in developing countries where the risk of loss is highest (Drucker *et al.*, 2005), and between 2000 and 2006 alone 62 breeds became extinct (FAO, 2007a). Such genetic erosion seems to be sustained by the ongoing spread of intensive livestock production based on a narrow range of highly-productive breeds with often very few sires used for breeding purposes (FAO, 2007b). An analogous situation exists for plant genetic resources. Paradigmatic examples are that of Mexico and China where since the 1930s 90% of all local maize varieties and 80% of all local wheat varieties have been lost, respectively (FAO, 1997). The 2009 FAO follow-up report explicitly noted that diversity in farmers' fields has decreased for some crops in certain areas and countries and that the threats to diversity are intensifying, partly due to climate change (FAO, 2009:4).

The threat of genetic erosion, as a consequence of narrowing the portofolio of crops (and breeds) used in farmers fields, in turn due to so-called 'agricultural modernization', is perhaps the highest for crops that garner little interest from breeders (known as neglected and underutilized crops), since genetic diversity tends to reduce when local varieties are replaced by improved cultivars. Hence, it is necessary to draw increased attention to the conservation of neglected and underutilized crop species (IPAGRI, 2002; Gruère *et al.*, 2009).

Besides supply-side factors that may hamper access to resources required to maintain socially desired agrobiodiversity levels (e.g., access to seeds by farmers), the main problem underlying biodiversity loss is demand-shaped (Tisdell, 2003; Bellon, 2004), underpinned by a mismatch between farmers' private conservation costs and wider societal benefits. Whereas agrobiodiversity management decisions are taken at the farm-level, with conservation costs (e.g., foregone agricultural productivity) incurred by individual farmers, a significant part of the benefits from agrobiodiversity conservation accrue at the landscape (community) and global levels. This is the typical market failure problem associated with the under-provision of public goods by market forces. Custodians of agrobiodiversity provide conservation services as a positive externality for which they are not rewarded in the marketplace (Friis-Hansen, 1999).

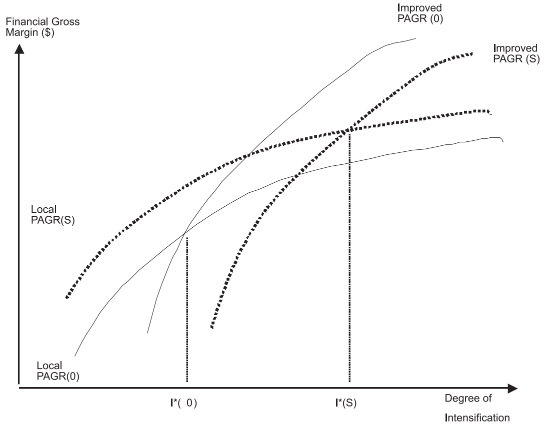
PAGR have an impure public good characteristic, with a private production component that is directly linked to farmers' decisions and a public genetic information component that is not (see Heisey *et al.*, 1997; Smale *et al.*, 2004; Eyzaguirre and Dennis, 2007). Since markets overlook the public value provided by agrobiodiversity conservation associated with the provision of insurance, adaptation, resilience and sustainagility at different temporal and spatial scales, thus underestimating the true social worth of PAGR, a suboptimal level of agrobiodiversity is conserved from a social point of view (Pascual and Perrings, 2007; Gruère *et al.*, 2009).

The weakest link of the value chain is at the farm level. This can be illustrated with plant genetic resources. The short-term value of natural insurance is often distorted due to subsidized commercial crop varieties, so poor farmers perceive relatively little private incentive to conserve genetic diversity (Perrings, 2001). The most profitable decision is frequently to grow only a few crop varieties, not investing in conservation of the varieties less 'favoured' by the market. Hence, where non-use (e.g., cultural) values are not sufficiently large to close the gap between the direct use value provided by the narrower suite of commercial varieties and the private insurance value provided by a wider range of genetic diversity, it is unlikely that farmers will conserve local crop varieties in the longer term, hence creating a social cost (Krishna *et al.*, 2010).

Besides the market failure associated with agrobiodiversity, there is a significant intervention or policy failure, epitomized through the bulk of subsidized inputs associated with intensive agriculture, free extension services or market price support related to high yielding or improved PAGR. This further distorts the incentives to conserve local PAGR (Drucker and Rodriguez, 2009). Figure 3, adapted from Drucker and Rodriguez (2009), illustrates the economic reason for the displacement of local PAGR by commercially improved resources (e.g., high yielding varieties from modern breeding programs), which narrows the range of genetic diversity of PAGR from agricultural landscapes.

FIGURE 3

Replacement of local PAGR by improved PAGR (Adapted from Drucker and Rodriguez, 2009)



A simple heuristic model illustrated in Figure 3 can show the market failure problem associated with the socially suboptimal level of agrobiodiversity conservation. Let's assume that a farmer's 'local' livestock breed or 'local' crop variety (local PAGR) would outperform a higher yielding or "improved" PAGR in terms of financial gross margin up to a given level of production system intensification[1] denoted by I* due to the agroecosystem characteristics that favour locally adapted genetic resources. Let's assume also that farmers have complete information about the market profitability of the improved and local PAGR (illustrated by the functions represented by the continuous lines). After I*(0) is reached, farmers face increasing financial incentives to replace the local PAGR with the improved ones. The magnitude of such incentives is determined by the vertical distance between the two curves, i.e. the financial opportunity cost (foregone benefits at current market prices) associated with the utilization of local PAGR.

However, there are a number of reasons which suggest that the current replacement point, I*(0), is located to the left of the socially optimal replacement point, say at level I*(S), i.e., I*(S) > I*(0). The difference between I*(0) and I*(S) reflects a market failure, due to not taking into account of significant non-market values associated with the conservation of local PAGR, compounded by an artificial overestimation of the performance of improved PAGR due to policy and intervention failures (for instance due to free availability of improved seeds, capital subsidies for inputs such as fertilizer or pesticides, free or subsidised support services, or subsidized market prices). In other words, in the presence of market, policy and intervention failures the current financial incentives are likely not to be in accordance with the real economic (scarcity) value of agrobiodiversity (i.e., including non-market benefits and

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[1] 'Intensity' is used in a broad sense and includes, *inter alia*, factors related to access to markets and extension services. Intensity thus is not related *per se* to the use of improved or high yielding genetic resources *per se*. See Narloch *et al.* (2011) for a fuller description of the model.

costs), resulting in the provision of agrobiodiversity conservation services at a level that is less than socially optimal (Heisey *et al.*, 1997; Pascual and Perrings, 2007).

From this heuristic model the solution to the social dilemma seems straightforward. Society should first demonstrate and design economic instruments so that farmers can capture the true (scarcity) value of local PAGR, that is the full economic value of agrobiodiversity that ought to include not only the direct use value but also the insurance, adaptation and sustainagility values which benefits society at large. In addition it should bring about regulatory policy interventions to reach the optimal replacement point (and thus optimal level of agrobiodiversity conservation services). In the model this is illustrated by accounting for the removal of subsidies to improved PAGR, which would shift the curve for improved PAGR downwards to the right (dotted line), and putting in place further mechanisms to permit the ‘capture’ of the total economic values associated with local PAGR, so as to shift the curve for local PAGR upwards to the left (dotted line). Such mechanisms could include niche market development for products associated with local PAGR, reducing transactions costs associated with accessing PAGR, as well as voluntary payments or rewards for the on-farm utilization of local PAGR. We turn to the potential role of one such economic instrument, payment for agrobiodiversity conservation services (PACS) in the penultimate section.

4. A policy toolbox for agrobiodiversity conservation under climate change

The importance of agrobiodiversity conservation services and the irreversibility of genetic resource loss motivate urgent action. The call for managing agro-ecosystems so as to generate diverse services including those from agrobiodiversity conservation has found widespread support (Swift *et al.*, 2004; Swinton, 2007; Jackson *et al.*, 2007; Scherr and McNeely, 2008). Although there is growing consensus on the need for the conservation of genetic diversity, concrete actions at a larger scale are thus far widely missing (Kontoleon *et al.*, 2009; Laikre *et al.*, 2010).

In agro-ecosystems, where farmers normally have well-established (formalized or customary) rights to use land (Eyzaguirre and Dennis, 2007; Howard and Nabanoga, 2007), agrobiodiversity conservation depends on encouraging people to apply certain practices on their farms. This is known as on-farm or *in-situ* conservation, which may be facilitated by institutional support or economic incentives, and leads to both conservation and enhanced farm-level adaptability to climate change, as discussed above. In recent years, *in-situ* agrobiodiversity conservation is being seen as a complementary strategy to *ex-situ* conservation in gene banks (Maxted *et al.*, 2002), with the former also being mandated by the Convention on Biological Diversity (CBD).

Next we discuss the advantages (and weaknesses) of *ex-situ* gene banks, followed by a discussion of the possible potential of hybrid *in-* and *ex-situ* mechanisms, drawing on the example mechanism of the community gene bank (CGB). Then the potential role of economic incentives that can make farmers capture the immediate private benefits from PAGR and thus invest in *in-situ* conservation for adaptation to climate change is discussed.

4.1. Ex-situ conservation

There are increasing efforts to sample and store local crop varieties and wild relatives *ex-situ* in seed collections (FAO, 2009). Such gene banks can function as a low-cost conservation instruments in order to safeguard genetic resources for many years, thereby avoiding loss through changing environmental or economic conditions (Wood and Lenne, 1997). These "accessions" find wide use in breeding programs (Smale and Day-Rubenstein 2002; Hodgkin *et al.*, 2003). Although a large proportion of the world's major crops can be found in these gene banks, many minor crops and crop wild relatives that are important for the livelihoods of marginalized people are not included (Padulosi *et al.*, 2002; Drucker *et al.*, 2005).

Another concern with *ex-situ* conservation refers to the static approach of maintaining a certain information stock, as opposed to enhancing the flow of information in a dynamic process through *in-situ* conservation (Swanson and Göschl, 1999). This is because key elements of genetic resources cannot be captured and stored off-site, including aspects related to their embodiment of ecological and social relationships (Brush, 1995). Genetic diversity in the field contributes to evolutionary processes (Faith *et al.*, 2010), whereby varieties with the same genetic material adapt to the specific agro-ecological conditions they are subject to, further conditioned by human selection (Perales *et al.*, 2003). This will be particularly crucial with regards to climate change. That is, as environments change, crops need to remain connected to them in order to adapt to novel climate regimes. Most importantly, *ex-situ*-conservation cannot safeguard the traditional knowledge associated with PAGR stored with famers (Brush, 1995; Stromberg *et al.*, 2010) and in local seed networks (Coomes, 2010). This also has a crucial role in climate change adaptation, as farmer ability to utilize new (to them) germplasm will be enhanced if it comes bundled with the information needed to grow it. Finally, *ex-situ* conservation often involves storing resources out of reach of their initial users - e.g., in national genebanks, while (as discussed above) farmers that have access to a more diverse variety of livestock breeds and crop varieties are best able to build more sustainable livelihoods through resilient production systems, reducing their food insecurity (Brussard *et al.*, 2010). In this way, *ex-situ* conservation enhances long-term adaptation to climate change by conserving option values but does not provide short-term insurance at the farm level in the face of climate shocks.

4.2. Community seed banks: A potentially innovative hybrid in- and ex-situ mechanism?

Mechanisms that not only conserve agrobiodiversity but also link it to farmer-users are particularly apropos in the climate change context. It is argued that in many contexts, particularly those where farmers face marginal and diverse agroclimatic conditions or rapidly changing market conditions, there is demand for agrobiodiversity from farmers. Yet this is currently not met by supply, especially where formal exchange systems play a main role in providing farmers with seeds and breeds (Lipper and Cooper, 2009). Consequently, breeding programs and systems underlying the exchange of PAGR are further areas for intervention. This section briefly discusses several options for doing so before highlighting one of particular promise, the community seed bank.

Agricultural research centres and extension agencies could facilitate access to a wide portfolio of PAGR (including new cultivars or breeds with important traits) and support farmers' experimentation with a variety of PAGR (Wood and Lenne, 1997). One way of doing so may be through participatory plant improvement programmes, in which breeders work with farmers directly to develop crops that meet their needs (Morris and Bellon, 2004; Lipper and Cooper, 2009). Local-level registers of information about varieties and breeds is a second option. Developed with the cooperation of communities, these initiatives document the range of PAGR already available in an area (region, country or landscape), usually including their traits (for consumption and production), so that farmers may easier choose amongst them (Smale *et al.*, 2004). Improving market channels and decreasing transaction costs so as to allow farmers to use the full range of PAGR is another area for research, currently undertaken in a number of case studies organized by FAO (e.g., Nagarajan *et al.*, 2007; Smale *et al.*, 2008).

As access to diverse seed is the crucial lynchpin in securing conservation (and use) of crop genetic resources, the seed sector is another pathway by which adaptation to climate change can be increased. One innovative intervention in this area is the community seed bank (CSB). The CSB is a collection of seed that is maintained and administered by a community of farmers itself (Almekinders, 2001). A CSB has two main goals: (i) to ensure the availability of planting material (requiring relatively large samples of seed) and/or (ii) to ensure the availability of genetic material in situations in which local varieties are lost, for example due to a climate shock (requiring relatively small samples of seed) (de Boef, 2010). In practice, the objectives of seed security and conservation are frequently combined (Engel *et al.*, 2008). In an intertwined climate change and need for food security context, this would be essential for both conservation of threatened varieties and facilitating adaptation via adoption of local varieties.

In a typical CSB system, seed is either collected from the local area or contributed by farmers. A sample is taken to a formal genebank (regional, national, or international) to be documented and used by breeders, and the remainder is available for farmers in the community to access, usually on a revolving seed supply basis, i.e., seed is borrowed during planting and returned, usually with interest, at harvest. They can also be used to re-introduce lost varieties by sourcing genetic material from the national collection and placing it in the local CSB. As pointed out by Almekinders (2001), by reintroducing lost local varieties and rescuing threatened varieties for storage in gene banks, a CSB establishes a functional link between *ex-situ* and *in-situ* conservation approaches.

Though still not widespread, CSBs exist in many different global contexts. One early example is a system set up to deal with hardship and famine in Tigray, northern Ethiopia, in 1988 (Berg and Abay in Thijssen *et al.*, 2008). A UNDP/GEF-funded project in 1994 resulted in an expanded network of twelve Community Gene or Seed

Banks across Ethiopia. In central Nepal, seed-loan CSBs aiming for 'farmer-led on-farm conservation' were established in 2003 to fight genetic erosion blamed on high technological intervention, high access to inputs and frequent natural disasters (Shrestha *et al.*, in Thijssen *et al.*, 2008). Examples also exist in Zimbabwe (Mujaju in Jarvis *et al.*, 2003), Bangladesh (Mazhar in Friis-Hansen and Sthapit, 2000), Indonesia, the Philippines and Cambodia (Bertuso *et al.*, in Almekinders and de Boef, 2000).

It is argued that CSBs offer a variety of benefits for farmers, including providing food security due to landraces' more reliable yields under adverse conditions (Balcha and Tanto in Thijssen *et al.*, 2008), allowing them to access otherwise unavailable varieties with desirable properties (Teklu and Hammer, 2005), and secure seed storage (Polreich, 2005). There have thus been calls to expand the CSB mechanism elsewhere (e.g., Sthapit *el al.,* 2006 in Thijssen *et al.*, 2008). Their benefits as a functional *in-* and *ex-situ* link would be heightened in a changing climate, and Sthapit *et al.* (2010), in particular, argue that CSBs may be a promising method to improve *in-situ* agrobiodiversity conservation for adaptation and conservation in the face of climate change.

However, Almekinders (2001) also notes that CSBs' true ability to reach their goals is uncertain. To date, most examinations of CSB schemes undertaken by their implementers have been largely positive (e.g., Feyissa in Friis-Hansen and Sthapit, 2000; Mujaju in Jarvis *et al.*, 2003). Meanwhile, outside evaluators and academics, others (e.g., Bezabih, 2008; Polreich, 2005) have suggested that the long-term sustainability of the CSB system seems doubtful without external financial incentives (Engels *et al.*, in Thijssen *et al.*, 2008).

Thus while CSBs may offer one potentially innovative avenue for securing PAGR conservation to facilitate adaptation to climate change and food security, they warrant additional investigation before being advocated wholeheartedly. If they do improve supply of diverse PAGR, this may be unsustainable without an accompanying increase in demand for these PAGR, facilitated by stronger PAGR property rights, discussed in the next section, and created, for example, by linking their services to compensation mechanisms, such as the PACS scheme discussed later in Section 4.4.

4.3. Property rights to PAGR

Another way of strengthening farmers' access to agrobiodiversity is through the allocation of property rights over local PAGR in the form of either (i) intellectual property rights or/and (ii) farmers' access rights (Bertachini, 2008). Through the latter farmers are granted the right to use the PAGR found on their farms and to trade it with breeding companies (Brush, 1998; Swanson and Goeschl, 2000). Intellectual property rights would protect genetic material embedded in local varieties and breeds. Where PAGR have often evolved from breeding processes involving genetic material from both farmers and private and public sector entities (Perales *et al.*, 2003; Salazar *et al.*, 2007), multiple rights would need to be assigned. In such a system various parties may have the right for exclusion thereby undermining farmers' rights and access (Ramana and Smale, 2004). Similarly, poor and politically disempowered farmers might be excluded if they cannot defend their rights against powerful actors such as multinational companies (Anderson and Centonze, 2007).

However, it is important to note that in a vertical industry, the location of a property rights assignment is a crucial factor determining the incentives for efficient levels of investment at various levels of that industry (Swanson and Göschl, 2000). In the context of (plant) genetic resources, the current assignment of property rights has been at the retail end of the pharmaceutical and plant breeding industries. The assignment of 'plant breeders rights' (PBRs) has consequently led to an increase in: (i) the number of research and development (R&D) programmes, (ii) the total number of plant breeders and (iii) aggregate amount of public and private R&D expenditure (see Swanson and Göschl, 2000:84). At the same time, however, there is no evidence that such investments have increased in the essential input activities that would maintain the needed flow of genetic resources into the future (e.g., habitat and biodiversity conservation). Hence, PBRs have tended to create incentives to invest at the end of the industry (i.e. the plant breeding sector) but not in the earlier parts of the industry (i.e. the genetic resource providers sector). This has had an impact on both efficiency and equity within the industry.

"Farmers' rights" have been proposed as a form of counterbalance to PBRs, leading to the protection of traditional knowledge and equitable participation in benefit sharing. Similarly for animal genetic resources, Drucker and Gibson (2003) conclude that any property right assignments that affect the relationship between livestock-keeper communities, livestock breeders and biotechnology R&D must therefore be considered carefully in the light of this experience. This would include any property rights assignment developed under the recently negotiated Nagoya Protocol of the CBD.

4.4. Payments for Agrobiodiversity Conservation Services (PACS)

Economic incentives have been integrated into international climate legislation (e.g., via the REDD mechanism) and can also be used to divert resources towards biodiversity conservation (Pascual and Perrings, 2007; Ring *et al.*, 2010). There may be several means of aligning private and social incentives for agrobiodiversity conservation. While the first step is to identify policy and intervention failures that lead to an economically unjustified neglect of local PAGR so as not to further distort conservation (Bellon, 2004), the second step is to create positive incentives for enhancing *in-situ* conservation of PAGR as recommended by the CBD Strategic Framework 2011-2020 (COP 10 Decision X/2).

As local PAGR are directly linked to agricultural output, market channels can provide farmers with the necessary incentives to conserve genetic diversity (FAO, 2007b). Niche market development may be a means to increase the financial profitability and thus competitiveness of local PAGR (Gruère *et al.*, 2009), whereby products from the utilization of these PAGR would be promoted through eco-labelling, certification or origin schemes, which highlight the specific attributes of agro-biodiversity related products (Hermann and Bernet, 2009). There is an increasing attention drawn to niche market development in order to sustain agrobiodiversity (Gruère *et al.*, 2009; Kruijssen *et al.,* 2009; Krishna *et al.*, 2010; Gautam *et al.*, 2011). However, it seems unlikely that niche markets could foster the utilization of the full variety of PAGR. Besides significant market set-up costs and potential geographic gaps between suppliers (in developing countries and rural areas) and likely demanders (in wealthier countries and urban areas) that will be particularly costly in a climate change paradigm of increased transportation costs, there are a numerous PAGR that are not characterized by desirable consumption attributes, such as specific tastes or nutritional values, but by production-related attributes, such as shock resistance or environmental adaptability. It may be the latter for which no market potential exists despite significant agrobiodiversity conservation services, in particular when facing climate change.

In these contexts incentive mechanisms have to be put in place that reward farmers who sustain those PAGR that provide important agrobiodiversity conservation services so as to correct for market failures due to the (impure) public-goods nature of PAGR. So-called Payments for Ecosystem Services (PES) may act as an incentive-based instrument realigning private incentives with social benefits (Pascual and Perrings, 2007; Jack *et al.*, 2010).

PES have widely been understood as a Coasean solution to the under-provision of ecosystem services (Muradian *et al.,* 2010; Pascual *et al.,* 2010; Pascual and Corbera, 2011). Wunder's (2006, 2007) well known definition of PES stresses the voluntary nature of the transaction of a *well-defined service* (or the land use necessary to secure it) between at least one *service provider* and *beneficiary*, if and when the provider secures service provision (*conditionality*). Due to the global public value of agrobiodiversity, farmers could be compensated through public (government-financed) payments, so that public entities would act as buyers on behalf of the service beneficiaries (Engel *et al*., 2008; Jack *et al*., 2010). To date the use of PES for the promotion of PAGR is limited. Examples include the EU support payments for threatened livestock breeds under Regulations 1257/99 and 1750/99, and a GEF-funded project in Ethiopia[2], both of which are PES-like although not described as such. The GEF project scheme paid farmers for conserving traditional varieties and provided compensation based on an incremental cost approach, in this case related to the yield gaps between traditional and improved varieties.

Here we argue that a nascent idea, so-called "payments for agrobiodiversity conservation services" (PACS), understood as a sub-category of agriculture-related PES that focuses on socially valuable yet threatened local PAGR, could be used to increase the private benefits from utilizing local PAGR on-farm through voluntary reward mechanisms (Narloch *et al*., 2011).

PACS would focus more on land management, i.e, what is cultivated, how much, where and when. The providers of agrobiodiversity services, and recipients of the rewards of their conservation efforts, are most likely to be found in low-intensity

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[2] Project entitled: "A Dynamic Farmer-Based Approach to the Conservation of African Plant Genetic Resources" (see http://www.gefonline.org/projectDetails.cfm?projID=351 for further details).

agricultural systems where there are serious risks of loss of the PAGR. With regards to the service "beneficiaries" (and thus the potential buyers of such services), the demand for agrobiodiversity conservation services is rather dispersed, reaching from local farmers and communities to consumers all over the world and society in general. However, as in most PES systems to safeguard regional or even global ecosystem services, government agencies would likely need to represent the potential buyers.

Related to the "conditionality" criterion of any PES program, PACS too would be associated with a number of generic institutional challenges (as per Wunder, 2006, 2007), which include issues related to baselines, verification of service delivery and sanctions in case of non-compliance. Furthermore, a careful assessment of PACS scheme interaction with existing formal and informal institutions (including land tenure rights), the definition of conservation goals (in terms of which PAGR are to be conserved and what might be considered to constitute a safe minimum standard or population), and potential trade-offs between economic efficiency and equity goals would all need to be considered.

As Narloch *et al.* (2011) point out, firstly, PACS schemes would need to start by carefully assessing the interaction of reward schemes with existing formal and informal institutions. Secondly, location-specific land tenure issues need to be considered carefully in order to avoid tenurial conflicts. Thirdly, PACS contracts would need institutional arrangements that deal with baselines, verification of service delivery and sanctions in case of non-compliance based on scientifically determined conservation goals defined in terms of which PAGR are to be conserved and what might be considered to constitute a safe minimum standard (SMS). However, such issues have only been dealt with, at best, to a limited extent in the literature on PAGR .

In a companion paper, Narloch *et al.* (2011) provide a quantitative evaluation of a PACS programme based on competitive tender through which farmers apply for conservation contracts in Peru and Bolivia. They argue that a community based tender approach may be an effective means through which farmers can determine the payments they require with the added advantage that farmers would be selected based on objective efficiency and not other subjective criteria as defined by intermediaries. Their PACS design offer farmers compensation payments or rewards for utilizing traditional and currently neglected crop varieties (landraces) of *quinoa* (*Chenopodium quinoa*) and such rewards are designed to counterbalance quinoa specialisation (into a few highly financially profitable varieties associated with the export market) that is eroding the wider quinoa diversity in the Andean region. In their paper, Narloch *et al.* (2011) demonstrate the importance of having multiple criteria for targeting farming communities and selecting varieties to be conserved through PACS while at the same time exposing the trade-offs between an efficient conservation and an equitable distribution of conservation funds.

While applying such a PACS approach specifically to facilitate agrobiodiversity conservation for climate change adaptation would be possible, it would require, at a minimum, extending their existing safe minimum standards concept (based largely on minimum areas and farmer number goals), so as to include goals of relevance to achieving spatially targeted outcomes at a landscape level. It might also be expected that the PACS scheme would have to encompass a wide diversity of PAGR, rather than that of single crop. In a climate change context, there would additionally be a need to design the scheme in such a way as to be sufficiently flexible so as to be able to respond to the changing agronomic suitability of specific locations. In some cases it might be possible that increasing opportunity costs and deteriorating agronomic suitability might make *in-situ* conservation strategies for some particular PAGR largely unviable, leading to those PAGR having to be abandoned from the PACS scheme portfolio and replaced with others as part of the adaptation strategy.

Furthermore, the provision of agrobiodiversity services related to the resilience of agro-ecosystems as an adaptation strategy to climate change will be difficult to measure and transaction costs associated with the exchange of such services are likely to be significant due to the dispersed location of service providers and beneficiaries. Thus, government agencies at a local, regional, national or even international level may need to represent the potential buyers.

5. Conclusions

In many parts of the world, climate change rates will likely exceed the adaptive capacity of a broad range of plant and animal genetic resources used in agricultural production systems. This mismatch between climate change rates and adaptive capacities of current plant and animal genetic resources will require adaptations of production systems. As part of their strategies to adapt, countries will need still more “outside” sources of diversity of the same species or new species entirely, thus creating increased genetic resources dependency. Furthermore, based on existing models, it is expected that due to global climate change, some countries’ climates will become similar to those that are currently being experienced by others countries nowadays. As such, while some countries may be headed towards future conditions that resemble those experienced by countries whose climate may be also shifting today, the actual investment in agrobiodiversity by the latter countries is crucial for the needed food system adaptation to climate change in the future of the former countries. Hence international cooperation/coordination between farmers, government institutions, and research agencies will be critical in order to support the moving of production system germplasm from present locations that have become unsuitable to future suitable areas as well as to support continued agricultural production in areas that will experience unprecedented climate-related stresses (Fujisaka *et al.*, 2009).

This paper has stressed the idea that agrobiodiversity conservation is crucial for adaptation to climate change, by enhancing the sustainagility of agro-ecosystems in the face of changes in temperature and rainfall regimes. We have further argued that this strategy ought to be seen as a key approach to enhance food security of a large share of the population living in marginal areas.

Based on the conceptual framework developed above, we point out that the social benefits from agrobiodiversity conservation accrue at the global (society at large, including future generations), agro-ecosystem (regional and local farming communities) and farm (household) levels. Across these scales, we have argued that agrobiodiversity conservation can provide natural *adaptation* and *insurance* to farm households as well as *resilience* to farming communities and *sustainagility* to society at large when confronted with climate change. Enhancing access to agrobiodiversity will thus be crucial for facilitating climate change adaptation. Mechanisms to do so require in-depth investigation.

Understanding the value of agrobiodiversity in terms of its contribution to food security under climate change and hence acknowledging the role of agrobiodiversity for economic development is a prerequisite to advance the design of instruments to capture the value of agrobiodiversity. These can then correct the perverse policy interventions and market failures that undermine maintaining this crucial 'green infrastructure' for the poor.

In this paper we outline various approaches that can be used to enhance agrobiodiversity conservation. First, while the role of *ex-situ* conservation could be an important way of enhancing long-term resilience of farming systems translated into significant global option values, it is argued that this approach in isolation cannot provide short-term insurance and adaptation in the face of climate change on the farm. Farming communities thus need companion measures. One such measure that is being experimented with in developing countries is related to the seed sector, and more specifically with the development of community seed banks. It is also argued that to sustainably improve the supply of diverse PAGR, the demand for such resources needs to be articulated and strengthened. One way suggested here is linking the positive externalities of PAGR with economic compensation for farmers. These would imply innovative agrobiodiversity conservation payment schemes.

We argue that the role of voluntary economic reward schemes, or so-called payments for agrobiodiversity conservation services (PACS) have the potential of becoming a new economic instrument to tackle market, intervention, and global appropriation failures associated with the public good characteristics of agrobiodiversity. As PACS has just begun to be experimented with, there is more research to be undertaken before PACS may become established in the conservation and development policy-maker's toolbox. We believe that such research is necessary to find new tools that can simultaneously enhance food security and the conservation of biodiversity in agricultural landscapes in the face of an increasingly uncertain future in which small scale farmers are most at risk in the face of climate change.

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