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Impact of liquidity constraint on the management of animal genetic resources by pastoralist herders

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Abstract

The improvement of pastoral livelihoods in the context of a highly uncertain economic and climatic future implies a double need for conserving livestock biodiversity and reaching productivity gains. *In situ* conservation through participative genetic improvement programs is a tool of choice for these sustainable development pursuits. In this regard, breeding goals chosen by pastoralist breeders can be classified in two broad categories : productivity-seeking or risk-alleviating. The latter aim was an important motive for the constitution of the present indigenous breeds while the former is often a rationale for their neglect. Understanding the balance can help finding the way to sustainable biodiversity management. Being the basis of pastoral livelihood systems, livestock shoulders many roles, among which that of savings may be considered central. Credit facilities lacking in these remote areas, breeders would thus sell part of their productive capital to invest in its improvement. The present model consists in a theoretical inquiry for the possible consequence of this polyvalence of livestock, productive capital and mobilizable saving, on the choice between the two above-mentioned breeding aims under liquidity constraint. A major outcome of the proposed model is the existence of a threshold herd size effect on investment in risk-control. This effect does not bear on investment in productivity and is no longer observed if credit constraint is relaxed. This threshold is thus proposed to entail the presence of an “erosion trap” for biodiversity and further recalls the difficulty to design a breeding program for a group of breeders with very diverse endowments. As a result, appropriate credit programs should be considered as an important key to adoption of breeding schemes for *in situ* conservation, and thus both their efficiency and viability.

Introduction

Pastoral systems cradled and harbor a wealth of animal breeds, showing diverse and possibly precious adaptive features. This tremendous diversity presently comes under threat through social upheavals, erosion of indigenous institutions and knowledge, environmental crises as well as continuous politic and economic pressure for sedentarization (Köhler-Rollefson, 1997; Goe and Stranzinger, 2002; Tisdell, 2003; Homann *et al.*, 2008). Facing this rapid erosion of biodiversity, the major grounds for genetic diversity conservation programs are the option value, i.e. the possible need for some genetic attributes to face future environmental or economic challenges, and the existence value, principally drawn from cultural and leisure use value (Roosen *et al.*, 2005). This widely spread viewpoint seems to imply a lack of present productive value for these breeds, their neglect then resulting from some inadequacy to their economic environment (Mendelsohn, 2003). Nevertheless, given the quasi-public good nature of livestock genetics, other mechanisms might come into play, explaining diversity loss where it was, however, useful, at least for part of the social groups involved. Indeed, marginal costs of producing an animal of a certain improved breed is quasi-zero and genetic progress is characterized by strong positive externalities, extensive herding systems leading to non-excludability from its consumption. Moreover, genetic determinism of resilience to several animal diseases implies that epidemiological positive spillovers also result from a selective breeding directed towards the improvement of such attributes. One might thus expect free-riding problem in genetic improvement/management under pastoral conditions that should account for part of the genetic erosion through the introduction of more productive and less resilient exotic breeds. As a matter of fact, genetic innovation has been previously spurred in an effective way and past activities of pastoral people has delivered the present array of highly adapted breeds, the poor productive performances of which are to ascribe as a rule of thumb to the general risk control objective of the breeders. Genetic improvement, through participative selection processes, appears as the most promising way of coping both with the urgent need for promotion of genetic diversity and with the need for progress in societies that should benefit from productivity gains in the context of an increasing pressure on pastoral resources. In situ conservation of indigenous breeds and their conjoint improvement entails the thorough consideration of breeding goals of pastoral herders. From an economic point of view, it can be considered that those objectives are to classify in two general categories: individual productivity and risk management. Obviously, the attitude of the livestock owners towards risk will govern this choice. The question of interest is here that of a possible effect of herd size in that respect. Indeed, a typical feature of livestock economics is the dual nature of animals as commercial and capital goods, which proved to have appreciable impacts on price elasticity in some production systems (Jarvis, 1974). In addition, in traditional pastoral societies, the animals does not only constitute a productive asset but is also a major form of savings, that can be mobilized when facing cash needs in the context of a liquidity constraint in such marginalized areas. Thus, the original postulate of this model is that the breeder, to join or impulse any improvement program (either through selective or cross-breeding), will incur costs that will be covered by liquidation of part of its capital. According to this postulate, herd size is expected to have some influence on the basic choice between productivity and risk management, the direction of which is here proposed to be modeled.

Empirical facts: indigenous breeding strategies

Genetic orientation of their livestock towards productivity *vs.* risk management keeps a pivotal role in the general strategy of pastoral herders coping with a harsh and highly variable environment. Several illustrations of these strategies are found in the literature. In Rajasthan, the Raika pastoralists are so reported to keep two breeds of sheep, the Boti and the Bhagli, the first being more resilient while the latter is more productive. When a bad year is expected, breeders cross their ewes with Boti rams to get stronger products while they prefer crossing their ewes with Baghli rams when good years are foreseen (Anderson and Centonze, 2007). In the Eritrea, the Beni Amer pastoralists used to adopt a breeding strategy directed towards milk production and docility, keeping relatively small production units of 60 to 100 animals. This strategy is clearly at odds with the strategy adopted in other regions of semi-arid Africa where resilience and high mobility (through the use of camels) or wilder behavior and defensive long-horned zebu cattle are favored, as well as larger herds (Dinucci and Fre, 2003). Good pastures and security conditions are expected to account for such a strategy. Indeed, facing a rise in insecurity due to civil strife, the increase in cattle raiders, a deterioration of the climatic conditions and agricultural encroachment, the Beni Amer pastoralists reconsidered their strategy, introducing the communal grazing (aggregating smallest herds) and turning their genetic management towards wilder animals by cross-breeding with the Sudanese Dohein breed (Wilson, 2009). A third example can be found in Southern Ethiopia where the Borana cattle pastoralists also include genetic management as part of their strategy to cope with changing environment and pauperization (Homann *et al.*, 2008). Interestingly, two cases can be distinguished according to the endowment of the breeders. The small herds of poorly endowed breeders do not allow the practice of mobility. These breeders are therefore forced to adopt a strategy of sedentary land use, breeding their stock towards smaller framed cattle in conjunction with small ruminants. Better endowed breeder may afford the higher mobility needed to cope with encroachment through the adoption of camels. Diversification is thus common to both strategies but orientations are clearly divergent.

The model

Assumptions and general model

A single breeder (i) has to choose between two strategies, productivity per head (c_i) and adaptation (a_i), understood as cash investments in livestock improvement.

$$S_i = \left\{ \; a_i, c_i \; \right\}$$

The adaptation strategy allows the reduction of risk level while productivity is modeled as a risk-increasing strategy. Rationale for this choice is partly biological as productivity traits can be considered to be negatively correlated with adaptive traits or as indigenous livestock is out-crossed to exotic breeds lacking an history of selection against local constraints. Productivity moreover entails economic risk because of an increased dependence on external inputs.

The utility function of the breeder consists of a product of the mean individual value of the animals (y, related to productivity) and the number of them. This herd size is the variable told to be of interest in the present model under liquidity constraint. The breeder is thus assigned a number n_0 at the beginning of the period, when its choice takes place. Given the liquidity constraint, strategy S_i is financed through the sale of a number v_i of animals at price P. The number of animals included in the utility function (n) is modeled as the number of surviving animals at the end of the period (n_{t+1}), drawn according to the binomial distribution Bin(n_t,p), with $n_t = n_0 - v_i$ and p the probability of survival. Risk management is thus inserted in the model by considering p as a function of the strategy S_i. The herder maximizes expected utility E(U).

The attitude of the herder towards risk, as proposed through this model, might be interpreted as an infinite aversion. This formal proposition is grounded in sociological literature describing the so-called "high reliability hypothesis" (Roe *et al.*, 1998). This hypothesis suggests that the behavior of pastoralists does not consist in coping with an exogenous risk but rather in a conscious control of the probability of loosing animals kept in very large herds for social status reasons. The herders are thus expected to minimize an endogenous risk as would do the manager of a nuclear plant, according to the original authors' metaphor. Although these authors oppose high reliability to risk aversion from a sociological point of view, the mathematical form given here to their high reliability hypothesis does not stray from the economic definition of risk aversion. The use of a binomial distribution to model survival implies that the risk affecting livestock is here to consider as perfectly uncorrelated between animals. The reality symbolized is therefore the risk of theft, aggression by predators, non-epizootic diseases, inability to efficiently feed on available resources and inadequacy of animal's conformation regarding mobility, the latter strategy being a more general one adopted by herders to control covariant risks as drought and epizootics.

$$\begin{aligned}
U_i &= n_{t+1}\,\overline{y} \quad with \quad n_{t+1} \sim Bin(n_t, p) \\
n_t &= n_0 - v_i \quad with \quad v_i = \frac{a_i + c_i}{P} \\
p &= p(a_i, c_i) \quad \in [0,1] \quad with \quad \frac{\delta p}{\delta a_i} > 0 \quad and \quad \frac{\delta p}{\delta c_i} < 0 \\
\overline{y} &= \overline{y}(c_i) \quad with \quad \frac{\delta \overline{y}}{\delta a_i} \geq 0 \quad and \quad \frac{\delta \overline{y}}{\delta c_i} > 0
\end{aligned}$$

Finally, the general optimization problem may be written

$$\underset{\{a_i, c_i\}}{\operatorname{argmax}}\; E(U) = n_t\, p\, \overline{y}$$

Model specification

Two functional forms had to be chosen to develop the general model. First, individual value of the animals was given the form of a classic Cobb-Douglas function. The values y, a_i and c_i being expressed in monetary terms, the exponents of this function thus correspond to the global return on investments in genetic improvement oriented towards adaptation or productivity, respectively. A gain regarding efficiency of the animal selection process, market organization for the delivery of livestock services necessary for maintenance of productive crossbred stock or the higher valuation on markets of the targeted characteristics can all be understood as factors increasing those exponents. For the sake of mathematical simplicity and to better underline forces at play in the process of erosion of livestock biodiversity, solely the strategy of productivity has been considered as truly valorized on markets. The probability of survival (p) has been modeled as an inverse logit function. The exponential terms were considered as simple linear combinations of the strategy variables, a_i and c_i, and herd size after liquidation for investment, n_t. Signification of the parameters is given in table 1.

$$\begin{aligned}
\overline{y} &= A_0\, a_i^{\beta_1} c_i^{\beta_2} \\
p &= \frac{\exp\{\alpha_0 + \alpha_1\, a_i + \alpha_2\, c_i + \alpha_3\, n)}{1 + \exp\{\alpha_0 + \alpha_1\, a_i + \alpha_2\, c_i + \alpha_3\, n)}
\end{aligned}$$

	Meaning
α_0	general security level (a high value means a low risk level)
α_1	contribution of investments in adaptive traits to risk alleviation (> 0)
α_2	contribution of investments in productive traits to risk amplification (< 0)
α_3	technical factors accounting for the risk increase due to greater herd sizes (< 0)
A_0	basic value of an animal on the market
β_1	contribution of investments in adaptive traits to market value of animals (= 0)
β_2	contribution of investments in productive traits to market value of animals (> 0)
n_0	available herd size before investment in ai and ci

Table 1: Meaning of parameters used in functional forms for the animal value y and probability of survival p.

Expected utility thus adopts the following form.

$$E(U) = n\, p\, \bar{y}$$
$$= \frac{\{n_0 - \frac{a_i + c_i}{P}\} \exp\{(\alpha_0 + \alpha_3\, n_0) + (\alpha_1 - \frac{\alpha_3}{P})\, a_i + (\alpha_2 - \frac{\alpha_3}{P})\, c_i\}\, a_i^{\beta_1} c_i^{\beta_2}}{1 + \exp\{(\alpha_0 + \alpha_3\, n_0) + (\alpha_1 - \frac{\alpha_3}{P})\, a_i + (\alpha_2 - \frac{\alpha_3}{P})\, c_i\}}$$

Optimization

The first order conditions for maximization of E(U) lead to the following expressions.

$$(\alpha_1 - \frac{\alpha_3}{P}) = -\{1 + \exp(...)\}\, \{\beta_1\, a_i^{-1} - \frac{1}{(n_0\, P - (a_i + c_i))}\} \quad (1)$$

$$(\alpha_2 - \frac{\alpha_3}{P}) = -\{1 + \exp(...)\}\, \{\beta_2\, c_i^{-1} - \frac{1}{(n_0\, P - (a_i + c_i))}\} \quad (2)$$

As we consider solely the case where β_1 is 0 and by noting
$(\alpha_1 - (\alpha_3/p)) = \gamma_1$ and $(\alpha_2 - (\alpha_3/p)) = \gamma_2$,
from (1) and (2), we obtain

$$c_i = \theta(n_0\, P - a_i) \qquad with \quad \theta = \frac{\gamma_1 \beta_2}{\{\gamma_1(1 + \beta_2) - \gamma_2\}} \quad (3)$$

The linear equation here above can be expressed as follows: after withdrawal of the amount invested in risk mitigation, wealth stored in the herd is allocated to productivity according to a coefficient θ, that is a function of risk parameters α_1, α_2, α_3, price P and efficiency of c_i in increasing productivity. From (3) and (1), we obtain

$$\gamma_1(1 - \theta)(n_0\, P - a_i) - 1 - \exp\{\alpha_0 + \alpha_3 n_0 + \gamma_2 \theta n_0\, P + (\gamma_1 - \gamma_2\theta) a_i\} = 0$$

It can be sought for behavior of the model for extreme values of a_i and c_i. In this respect, a lack of investment in a_i may occur under conditions of liquidity constraint as shown by the following expression (in which n^{sa} stands for threshold herd size for investment in a_i).

$$\gamma_1(1 - \theta)\, n_0^{sa}\, P - 1 - \exp\{\alpha_0 + \alpha_3 n_0^{sa} + \gamma_2 \theta n_0^{sa}\, P\} = 0 \quad (4)$$

Conversely, a zero value of c_i would imply that $a_i = n_0 P$, which is not achievable except under the trivial case where n_0 also adopts a zero value.

Relaxed constraint

Liquidity constraint was relaxed by assuming an access to credit for amounts that can be guaranteed by total herd size. In this way, the wealth effect on investment is not abolished and the modification of the general model more specifically addresses the impact of the need for selling animals from the herd to invest in its improvement. Costless access to credit is assumed so that the herder maximizing its expected utility through investment in a_i and c_i will make use of all the available credit. Thus, we consider $n_t = n_0 = a_i + c_i$. The expected P utility function thus becomes

$$E(U) = A_0 a_i^{\beta_1} c_i^{\beta_2} \{\frac{a_i + c_i}{P}\} \frac{\exp\{\alpha_0 + (\alpha_1 + \frac{\alpha_3}{P})\, a_i + (\alpha_2 + \frac{\alpha_3}{P})\, c_i\}}{1 + \exp\{\alpha_0 + (\alpha_1 + \frac{\alpha_3}{P})\, a_i + (\alpha_2 + \frac{\alpha_3}{P})\, c_i\}}$$

And maximization program delivers the following expression.

$$(\alpha_1 + \frac{\alpha_3}{P}) = -\{1 + \exp(...)\}\{\frac{1}{(a_i + c_i)}\}$$

Cases where a_i or c_i would be zero would imply

$$(\alpha_1 + \frac{\alpha_3}{P})n_0 = -\{1 + \exp(\alpha_0 + (\alpha_2 + \frac{\alpha_3}{P})\, n_0)\} \qquad if \quad a_i = 0$$
$$(\alpha_1 + \frac{\alpha_3}{P})n_0 = -\{1 + \exp(\alpha_0 + (\alpha_1 + \frac{\alpha_3}{P})\, n_0)\} \qquad if \quad c_i = 0$$

As n_0 cannot take negative values, $(\alpha_1 + (\alpha_3/P))$ should then be negative. However, the latter proposition is not expected to occur if parameters settings have to consider as possible the alleviation of risk due to herd size (α_3) through improvement of the animal capital (α_1). Quite intuitively, it can be understood from those equations that no situation where a_i or c_i is zero can occur if access to credit is allowed.

Herd size threshold

As a threshold for investment in risk control has been detected in conditions of liquidity constraint, it might be of interest to consider under the present model the impact of different parameters on this threshold. From the implicit function describing threshold evolution (equ. 4), effect on n^{sa} of a decrease of the overall security level (α_0, might correspond to a climate felt by herders to be more and more erratic or for civil strife) and of an increase of risk due to herd size ($|\alpha_3|$, accounting for diverse real situations as an increase in thefts).

$$\frac{\delta n_0^{sa}}{\delta \alpha_3} = -\frac{\frac{\delta f}{\delta \alpha_3}}{\frac{\delta f}{\delta n_0^{sa}}} = \frac{n_0^{sa}\{(\theta(1-\frac{\gamma_2}{\gamma_1}) - \theta^2(1+\frac{\gamma_2}{\gamma_1}) - 1)\exp\{\alpha_0 + \alpha_3 n_0^{sa} + \gamma_2\theta n_0^{sa} P\} - 1\}}{(\alpha_3 + \gamma_2\theta P)\exp\{\alpha_0 + \alpha_3 n_0^{sa} + \gamma_2\theta n_0^{sa} P\} - \gamma_1(1-\theta)P}$$

$$\frac{\delta n_0^{sa}}{\delta \alpha_0} = -\frac{\frac{\delta f}{\delta \alpha_0}}{\frac{\delta f}{\delta n_0^{sa}}} = \frac{\exp\{\alpha_0 + \alpha_3 n_0^{sa} + \gamma_2\theta n_0^{sa} P\}}{\gamma_1(1-\theta)P - (\alpha_3 + \gamma_2\theta P)\exp\{\alpha_0 + \alpha_3 n_0^{sa} + \gamma_2\theta n_0^{sa} P\}}$$

As already exposed, γ_1 is expected to be positive while γ_2 is always negative by definition. The composed parameter θ, which represents the opportunity for herders to invest in individual animal productivity is thus always positive. Both expressions so adopt positive values meaning that threshold herd size for investment in a_i is decreased when risk increases.

Discussion

The present model aimed at a theoretic investigation of the impact of liquidity constraint on a breeder's choice between productive and risk-controlling traits in its herd. Indeed, it could be observed in the literature that animal genetic resources were an important component of strategies adopted to face environmental, sociological and economical challenges. Considering the whole livestock-based livelihood system and the complex strategies implemented, animal genetics might even be conceived as central to those as it involves a modification in the nature of the capital good on which production is founded. Thus, the context of this theoretic enquiry was that of the domestic biodiversity erosion and the need for conservation programs to include improvement aspects in accordance with breeders' objectives. However, no specific element of the model does restrict its implication to the study of the genetic make-up of an extensive herd. Therefore, any strategy that can be classified as productivity- and risk-increasing or as risk-alleviating but productivity-neutral can be integrated in this framework. In this context of animal genetic resources management and improvement, the point of interest addressed through this model was the impact of liquidity constraint, i.e. the need for the breeder to sell part of its capital to meet improvement objectives, on the direction of the strategy adopted, classified regarding its effect on productivity and risk-control. More specifically, the question of the herd size effect, and thus the wealth of the breeder, was tackled through this model.

A central outcome of this model is the existence of a threshold effect of herd size on investment in risk-alleviating traits under liquidity constraint that is not observed when access to credit is allowed and that does not affect strategy regarding productivity. Where thresholds are, poverty traps are expected to occur. Poverty traps are an important feature of livestock-based livelihood systems, e.g. linked to threshold effects in herd reproduction (Lybbert *et al.*, 2004). Events that force the breeder below such a threshold herd size dramatically affect its future by jeopardizing the accumulation process or numerical productivity. It is here suggested that a similar poverty trap exists regarding incentives for risk control. Below a certain level of endowment, the breeder would be lead to neglect risk-alleviation by the need for capital liquidation to meet the incurred costs. The latter observation is rendered all the more notable by the extreme form of risk aversion that is considered in this model.

As exposed among the empirical facts retrieved from literature, access to mobility is a critical parameter in the determination of a breeding strategy in evolving pastoral systems (choice of species, breeds and breeding traits) (Dinucci and Fre, 2003; Homann *et al.*, 2008). Mobility was itself told to be allowed by sufficient endowment of the breeder to afford the investment in expensive genetic resources as camels (Homann *et al.*, 2008). The same study describes that breeders lacking access to mobility adopted an "intensification" strategy, rather resulting in pauperization given defective access to production factors and poverty traps inherent to livestock rearing. Human and environmental harm that results from this process can be viewed under the present framework as directly linked to the liquidity constraint that such breeders have to face.

As regards livestock biodiversity concerns, because of the overlap between the different stylized dualities at play (selection *vs.* cross-breeding, indigenous *vs.* exotic breeds and productivity *vs.* risk-alleviation), the suggested poverty trap might be translated to an « erosion trap ». Rather than focusing on the role of a priority given to productivity motives for local breeds neglect, it could thus be understood that credit constraint impedes investment in an asymmetrical way, skewing breeder's choice towards productivity and against adaptation.

Quite tautologically, participative genetic improvement programs cannot overlook breeders objectives that constitute the heart of their legitimacy, usefulness, efficiency and viability. In this regard, breeding traits are valued according to different methods, including choice experiments that allow valuation of traits in the absence of markets for them. The breeders objectives as handled in this model refer to the more general consequence of those traits and do not lend themselves to practical application. This theoretical approach rather highlights the upstream role of access to credit in the value attributed to traits according to their risk-alleviating or productivity-increasing nature. It moreover calls attention to the difficulty of integrating breeders with very different endowments in a same improvement program and the possible role for appropriate credit facilities in this prospect.

Finally, the case of liquidity constraint in extensive livestock keeping in developing countries might be rephrased as a case of liquidity constraint in a situation where a same asset embodies the savings of an agent, the main source of utility to him and the capital in the improvement of which he may invest. Addressing this quite specific case allowed the identification of a potentially important factor of erosion of animal genetic resources, that should be added to those enumerated in the introduction.

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