THE ECONOMICS OF CAIN AND ABEL:
AGRO-PASTORAL PROPERTY RIGHTS IN THE SAHEL

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FOREWORD

The importance of pastoral production systems is often overlooked by donors and policy makers, many of whom argue that the nomadic lifestyle is no longer viable. The empirical facts suggest, nonetheless, that as much as one-quarter of the West African population are in fact pastoral, and that 30 to 40 percent of the agricultural value added in the Sahel is attributable to livestock production.

One of the underlying causes of the seeming skepticism or underestimation of the role of nomadic peoples undoubtedly emanates from the long-standing conflicts between nomads and farmers. Indeed, the complementarity of the economic systems of nomads and farmers, manifested in the exchange of productive output, has generally been overshadowed by the conflicts inherent in the competition over the control of land.

The conflict is essentially one of property rights. In order to better understand the nature of this conflict, this paper initially describes the agro-pastoral production system of the West African Sahel. This is followed by the presentation of a model that simulates the emergence of a dual economy based on the comparative advantage of farmers and pastoralists. In doing so, the paper establishes two points. First, it points to the fact that exclusive private property rights have no monopoly on economic optimality. The analysis of risk in an intertemporal framework points to the value of another type of property right – the right to adjust. Second, the latter property right is of crucial importance to livestock production in Sahelian West Africa and as such to the livelihood of millions of people in the region. The structure of property rights – entitlements – determines the winners and losers of economic reform. Thus, the analysis contributes directly to the larger CFNPP research program in that it draws our attention to the specific institutional context in which reform takes place. Additionally, identifying the structure of property rights also forms the point of departure for the modeling exercises that the CFNPP undertakes in order to identify welfare effects of policy reform presently under way in Africa.

Recent upheavals in Mali involving the Touareg nomads highlight the actuality of the issues addressed by van den Brink, Bromley, and Chavas in this working paper. Moreover, there is growing anecdotal evidence that the rejuvenation of indigenous institutions is a significant side effect of many economic liberalization programs in sub-Saharan Africa. In general, the study of the impact of economic reform on the poor should not take place in an institutional vacuum. It is hoped that papers such as this one will contribute to fill this void.

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David E. Sahn
Deputy Director, CFNPP

1. INTRODUCTION

Nomads and farmers seem to have been in conflict throughout history and throughout the world. In fact, one Hebrew version of the Biblical story of Cain and Abel provides the first recorded clash between a nomad and a farmer.[1] In some respects, conditions today are not much improved. Conflicts between nomads and farmers continually recur. However, next to conflict, complementarily is also a structural characteristic of the dual economy represented by Cain, the farmer, and Abel, the pastoralist. The two economic systems complement each other with respect to the exchange of outputs but seem to be continually at odds with one another over inputs, especially over the control of land use.

The conflict should be understood as one of property rights. In agriculture as well as livestock production, property rights emerge to secure income streams generated by production activities. The nature of the income stream, then, may affect the type of property right that is likely to be established. The crucial difference between sedentary farming and nomadic livestock production lies in the extent to which the respective production techniques induce exclusive property rights with respect to a particular location. In Africa, as well as elsewhere, cultivation rights of farmers are property rights which, by virtue of the underlying farming technique, are territorially more exclusive than the typical pastoral property rights of grazing, watering, and passage.

The economic value of territorial exclusivity of certain property rights is derived from a basic distinction between the production techniques of nomads and farmers. They differ in their ability to react ex post to temporal uncertainty, or, in other words, they differ in flexibility. The concept of flexibility has only recently drawn the attention of economic analyses of risk in an intertemporal setting (see, e.g., Epstein 1980; Dreze and Modigliani 1972). Economic theory has generated an extensive literature on the effects of risk on economic decision making. However, risk is commonly modeled as if it were

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1 "Some say that the quarrel arose at Earth's division between the brothers, in which all land fell to Cain, but all birds, beasts and creeping things to Abel. They agreed that neither should have any claim on the other's possessions. As soon as this pact had been concluded Cain, who was tilling a field, told Abel to move his flocks way. When Abel replied that they would not harm the tillage, Cain caught up a weapon and ran in vengeful pursuit across mountain and valley, until he overtook and killed him" (Graves and Patai 1964, 91).

"timeless." In this context, the individual is forced to make a decision ex ante, i.e., before the uncertainty is resolved. The formulation of the problem in terms of timeless risk precludes the theory to investigate important economic behavior such as learning–actively and passively–and adaptive strategies–a set of dynamic decisions that are influenced by new information as it becomes available. Once we introduce temporal uncertainty, a wider variety of economic behavior under risk can be modeled. Moreover, risk preferences have played a prominent role in studies that focused on ex ante risk reduction, notwithstanding the difficulty of the direct measurement of risk preferences. One advantage of the formulation of economic theory under temporal uncertainty is that it establishes the value of information or the value of an adaptive strategy for any risk preference.

If economic institutions are a response to uncertainty, it seems logical not to restrict our attention to one type of risk. In other words, the recognition that uncertainty is not timeless, but resolves over time, is important for the analysis of economic institutions, in general, and property rights, in particular. If a farmer puts up a fence around his fields and establishes an exclusive private property right to the land, he reduces a particular type of uncertainty. He reduces the risk that others may claim the field, and he assures himself of the full benefits of any investments he would care to undertake in his fields. He establishes ex ante certainty to the exclusive use of the land. The higher and the more certain the income stream he can derive from the exploitation of his field, the more he will be willing to pay for the "fence," i.e., the exclusive private property right.

However, where there is ex post uncertainty, there is a positive economic value attached to the capacity to adjust ex post. Thus, the ex ante "certainty," which a nomadic pastoralist would acquire by fencing his range in a situation of extremely variable rainfall and a limited potential to improve the productivity of the range, does not represent a high economic value. The nomad, then, might not be interested in an exclusive private property right to a particular field. He might be more interested in establishing a property right that would enable him to ex post adjust to temporal uncertainty. In particular, he would value property rights that assured him mobility.

Such property rights are no less property rights than exclusive property rights. They assure the property right holder of a secure income stream. From a pastoralist perspective, then, establishing "tenure security" means establishing the security of such property rights as are best suited to capture the income stream of a mobile economic activity. However, in the context of the Sahel, we submit that pastoralist property rights have been considerably eroded. Ever since the publication of Sen's (1981) seminal essay on the relation between famines and entitlements, the implications of the loss of property rights to nomads hardly need elaboration. Not only has such erosion led to an increase in transaction costs of the nomadic enterprise, but it has also affected the pastoralists' ability to overcome periods of drought.

The paper consists of four parts. The first part of the paper describes the agro-pastoral production system of the West African Sahel. Emphasizing the universal nomad-versus-farmer problem, the second part of the paper models the West African reality as the dual economy of Cain and Abel. The model simulates the emergence of a dual economy based on the comparative advantages of two different production techniques faced with environmental uncertainty. An economic theory of optimal production techniques and property rights is developed in a context of dynamic risk. The third part of the paper touches upon policy issues, both in a historical as well as in a current framework. Conclusions are drawn in the fourth part.

2. THE AGRO-PASTORAL PRODUCTION SYSTEM OF THE SAHEL

Even in enlightened circles the "nomadic dilemma" is seldom understood as a problem of property rights, but, rather, as one of nomads "lacking modern education, ignoring frontiers and spreading cattle diseases" (Adamu and Kirk-Greene 1986, xiii). Additionally, "Pastoral nomadism tends to be regarded as anachronistic, unconducive to good administration or education, and is expected to be superseded in time by 'resettlement' programmes" (Mortimore 1989, 223). Thus, a commonly held assumption is that nomadism is ultimately doomed and that efforts should be geared towards making this outcome as painless as possible (e.g., Lowe 1986). This attitude is best illustrated by a proposal for a principal motion at the Fifteenth International African Seminar on Pastoralists of the West African Savannah:

> The conference notes that the nomadic aspect of the life of pastoralists is no longer tenable in the face of ever greater pressure on land, and that it is not in the interest of the pastoralists themselves to continue to lead a nomadic or semi-nomadic way of life. The conference therefore recommends the governments of the various countries in which these people are found to encourage and actively aid their permanent settlement, the modernization of their methods of husbandry and to include animal husbandry in agriculture development programmes, while at the same time taking care to preserve whatever is worth preserving in their culture, including their languages (Adamu and Kirk-Greene 1986, xvii).

The empirical reality of the effectiveness of pastoral production systems provides a stark contrast with the above presumptions. Maybe as much as 25 percent of the total population of West Africa can be classified as pastoral (Sihm 1989). In Sahelian West Africa (Senegal, Mali, Burkina Faso, Niger, and Chad) livestock production typically accounts for 30 to 40 percent of total agricultural value added. Shapiro (1979) estimated that cattle originating in Mauritania, Mali, Burkina Faso, Niger, and Chad supplies more than 50 percent of all slaughter cattle in the wider West African region. These "low-productivity" Sahelian livestock production systems operate at levels of animal protein production per hectare that significantly exceed the levels for comparable regions in the United States and Australia (Breman and de Wit 1983). The supposedly "subsistence oriented" and "backward" pastoralist economy supplies all major urban centers in West Africa with a steady and increasing flow of meat (Swift 1986). This flow is made possible largely by an elaborate and effective international trading network that links the

Sahelian producers with the major consumption centers on both sides of the Sahara desert. Moreover, the nomads' alleged poverty and backwardness do not seem to prevent the levy of a plethora of taxes on cattle trade in an effort to boost government revenues. Finally, one could argue that the success of the Sahelian livestock production system in meeting urban consumption at competitive prices has largely been achieved not as a result of, but in spite of possibly well-intended development policies, such as ranching projects and settlement schemes (Hogg 1987; Sandford 1983).

Gorse and Steeds (1987) describe the rainfall regime of the West African savannah ecosystem as follows: The Saharan North is characterized by extremely variable rainfall, less than an average of 200 millimeters per year. As one moves south, rainfall patterns become more stable, with average rainfall increasing to more than 800 millimeters for the Guinean savannah zone. The Sahel can roughly be described as a transition zone between the Sahara and the Sudanian zone. Depending on the rainfall pattern of a particular year, a "Northern Limit of Cultivation" (NLC) exists. The NLC falls, on average, somewhere between the 200 and 350 millimeter isohyets (average rainfall isocurves). Population densities across zones vary from 0.3 to 20 persons per square kilometer (1980 estimates), reaching a minimum in the arid north and a maximum in the Sorghum Belt, i.e., the northern and middle Sudanian zones. The area further south is generally less densely populated: the tse-tse fly renders certain regions nearly uninhabitable for cattle. Additionally, crop production in the Guinean zones is negatively affected by the interaction between the shorter length of the dry season and increased leaching of the relatively shallow soils.

The north-south sequence of agricultural resource exploitation varies with the climate. Pure pastoral nomadism, practiced in the arid north, is conceptually defined as a perfectly mobile system of extensive livestock production with virtually no permanent place of abode and no crop production. (An exception is oasis crop production, practiced wherever possible.) Moving south, one finds the fully mobile livestock production gradually associated with some form of crop production. For instance, nomads may sow some plots at the beginning of the rains and move north with their herds in search of pasture, leaving the sown plots unattended until their return at the end of the season. Alternatively, a section of the nomadic population may cultivate some crops on valley-bottom lands during the short rainy season, while the other section accompanies the herds on their seasonal movements. Such a system may be classified as seminomadism. Much of the southern Sahel is characterized by transhumance systems. Under the latter system, trek routes are shorter, while part of the population is sedentary and engaged in crop cultivation. Livestock production, however, remains the dominant economic activity, and only one-tenth of West African cattle can be attributed to completely sedentary livestock production systems (Shapiro 1979).

A pastoral clan may employ several routes to move from dry season pasture in the south to rainy season pasture in the north. In general, trek routes are "anchored" on one or more relatively sure waterpoints, such as a lake or a flooded valley. The routes can range between 100 and 400 kilometers. Because average rainfall increases, and variability of rainfall decreases, in a southerly direction, the more southern Sahelian transhumance systems employ shorter routes. However, multiyear periods of extreme and prolonged drought are a recurrent phenomenon across the Sahel, and they trigger movements over long distances. It is not unusual for such migrations to cause the crossing of several national borders, while the return to the original country may only occur several years later. The existence of such "drought contingency routes" is a vital part of any pastoral strategy in the Sahel (Starr 1987).

Empirically, a positive relation between observed mobility of pastoralists and the riskiness of the environment emerges. Spatial flexibility in response to ecological conditions is the crucial characteristic of livestock production systems in the highly variable climates of the Sahel:

> It is now widely conceded that few can compete with nomadic pastoralists in the efficiency of their adaptation to the spatio-temporal variability of the arid habitat (Mortimore 1989, 215).

Thus, comparisons between nomadism/transhumance and sedentary livestock production invariably show greater animal productivity under the former production modes (Penning de Vries 1983).[2]

Two countervailing forces oppose southward movements of pastoralists. The first is the incidence of diseases detrimental to human and animal health, such as river blindness and trypanosomiasis. The second countervailing force is the increase of the farming population density, which reaches its maximum in the so-called Sorghum Belt, where Sahelian population centers, such as N'Djamena, Kano, Sokoto, Niamey, Ouagadougou, Ouahigouya and Bamako, are found. Thus:

> The interactions between rainfall and human and animal health have resulted in population densities being the greatest in drier areas where health hazards are limited, but so are production possibilities (Lele 1988, 193).

In economic analysis, farming is usually seen as a set of production activities in which production decisions are made ex ante. Empirically, farmers in the semiarid tropics have adopted a number of techniques that

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[2] In Botswana, comparisons with ranching show that the production of protein per hectare under the traditional production system is significantly higher (de Ridder and Wagenaar 1984).

stress ex ante risk reduction. Such techniques typically include intercropping and plot scattering. These tactics can be seen as an attempt by the farmer to reduce risk. Additionally, risk reduction can be obtained through portfolio diversification by choosing assets that exhibit low or negative covariances with respect to each other. However, farmers in the semiarid climates of the West African savannah, like herders, value temporal flexibility (e.g., Warren and Maizels 1977). For example, shifting cultivation and several types of rotational farming exploit the variable productivity of the resource base. In the dryer areas, farms may actually move around from year to year. In Niger, one observer described the farming system as "agricultural nomadism" in view of the continuous movement of farms in search for fertile soils (Cissé 1982). Even intensive and sustained manuring may not allow for permanent cultivation; the compound and the animal parkings are continuously moved in a rotational pattern so as to spread the benefits of manuring and to avoid overexploitation of a particular plot (Thompson 1982).

A closer look at property rights regimes associated with pastoral production systems, will show that the capacity for flexibility in movement is at the basis of their definition. Property rights of pastoralists emphasize the possibility for contingent, i.e., state-dependent, movements. Such property rights regimes typically do not attempt to establish exclusive rights to a particular piece of land *per se*. Thus:

> The pastoral Fulani displayed little concern with territorial identity or the defence of particular grazing areas; they were more interested in rights of access to pastures, water, and salt for their cattle than they were in the ownership of land (Frantz 1986, 18-19).

Typically, the tribal organization of a nomadic property regime enables each economic unit to be continuously mobile since no single, permanent trek route would be optimal under environmental uncertainty. The property regime, then, does *not* define a fixed territory for its members (Clanet 1975). On the contrary, the relational aspects of property rights are stressed, as pastoral peoples need to continually move around (Neale 1969). Movements need to be coordinated with other lineages and tribes, as well as with farming populations. Thus, the Pastoral Fulani:

> ...appointed Functionaries whose duty it was ... to herald the approach of the herds and to give gifts of milk and butter or of bulls for slaughter to the (people) in whose territory pasture was sought (Stenning 1960, quoted in Franke and Chasin 1980, 46).

The different itineraries of annual transhumance may be coordinated in advance by an assembly of lineages in order to minimize the risk of interference. Under such property rights regimes, lineage heads function as stewards of the system, while cattle are private property (Lainé 1982). The lineages thus form a management group that establishes rights and duties with respect to the use of pastoral resources (access to trek routes, pasture, water, et cetera). Nomadic property rights regimes, then, achieve a mix between individual incentives and group incentives mediated by—indeed, defined by—institutional rules.

Even the more "sedentarized" pastoralists of the southern Sahel who practice restricted seasonal movements within, for instance, zones of 30 to 50 kilometers, will typically not claim exclusive property rights to their potential grazing area. Lineages' management rights constitute property rights that are not directly exclusive in terms of territory: they define priority access rights to water and pasture. The management right of lineage, however, needs to be asserted or "activated" by the digging of wells, the erection of camps, and actual grazing. To the extent that nonmembers do not interfere with members' management and access rights, nonmembers also have access to the resources. The priority access to water will effectively regulate the usage of the territory by nonmembers under adverse environmental conditions. Territorial exclusion, then, is indirectly achieved when needed by controlling the access to the crucially scarce factor but not by directly claiming exclusive territorial title to the land as such.

In summary, the agro-pastoral production systems of the semiarid savannah typically incorporate a mix of mechanisms that allow for adaptive strategies to changing environmental conditions. Instead of making all production decisions ex ante, which would preclude the use of new information, the producer adopts a strategy that allows him or her to react to the temporal resolution of risk (Chavas, Kristjanson, and Matlon 1991). In other words, the strategy of the enterprise allows for decision making in response to new information about input availability. In the case of nomadism, the economic value of such flexible strategies has found its expression in actual spatial movement of the production unit, i.e., "spatio-temporal flexibility," by which we mean the physical movement of the enterprise after new information becomes available. Empirically, one can observe a relation between the riskiness of the environment and the extent to which spatial flexibility as an adaptive strategy to temporal risk is incorporated in the production system. Spatio-temporal flexibility is less important to farming than it is to nomadism. Given the limited potential for spatial flexibility of farming systems, temporal flexibility and various ex ante risk minimizing mechanisms assume vital importance. Just as livestock production gradually becomes less mobile as one moves south and rainfall patterns become more stable, farming systems, too, place less and less emphasis on spatio-temporal and temporal flexibility.

3. A MODEL OF AN AGRO-PASTORAL PRODUCTION SYSTEM

In the following, an economic model is presented that captures the dominant characteristics of the production systems of nomads and farmers as described above. The model simulates the emergence of a dual economy based on the comparative advantages of two different production techniques with respect to environmental uncertainty.[3] The two techniques differ in their capacity to react to temporal risk. A technique-dependent induced demand for property rights is derived. The transformation of this demand in monetary terms leads to the definition of the "willingness to pay" (WTP) for a specific property right that secures the full profits of a particular production technique. Nomadic property rights capture the benefits of a technique that is based on ex post adjustments to environmental variability. We will call such a property right nonexclusive. Cultivation rights capture the benefits of a locationally fixed production technique. Such property rights will be called exclusive property rights. The use of the term exclusive, then, applies to permanent territorial exclusivity. Choice of technique and choice of property regime become a function of particular eco-zones (Bromley 1989).

In this model, the climate in the world inhabited by the farmer, Cain, and the nomad, Abel, is not a constant, but a variable. The north is arid with average annual rainfall of 100 millimeters and rainfall is extremely variable. Moving south, average rainfall increases while the variability is reduced in a parallel fashion. The furthest southern point is the 1,000 millimeter isohyet. Each isohyet runs perfectly west-east over the region. Thus, movements along a particular isohyet do not cause changes in mean or variability of rainfall. The simulated rainfall regime incorporates this basic pattern.[4] Every grid on the imaginary map (Figure

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[3] To simulate results, a computer model was developed using the matrix language Gauss. A description of the specific functional forms is given in the Appendix. The graphs that accompany the main text are based on this specific model.

[4] The rainfall regime described above was simulated using Gamma distributions. A random variable **e** has a gamma distribution with parameters α and β ($\alpha \geq 0$ and $\beta \geq 0$) if **e** has a continuous distribution for which the probability density function

$$h(e|\alpha,\beta) = \{\beta^{\alpha}/G(\alpha)\}e^{\alpha-1}\exp^{-\beta e} \qquad \text{for } e \geq 0$$
$$0 \qquad \text{for } e \leq 0$$

(continued...)

1) will fall under some specific rainfall distribution. Laterally (i.e., grids from west to east on a same isohyet), each grid exhibits realizations from probability density function with the same moments. North-south movements perpendicular to the isohyets exhibit realizations drawn from density functions that incorporate simultaneous changes in E(e) and Var(e). The variable climate defines different eco-zones and is central to the following model.

Cain and Abel live in a two-period world in which it rains in both periods. To optimize fodder availability for his herd, Abel attempts to stay mobile perpetually (i.e., for two periods in our model). Given actual rainfall in period 1 (represented by the realization of the random variable **e**) he makes his location decision x_1. This may also be called his ex ante choice. After Abel has observed rainfall in period 2, he decides to move his herd to a new location x_2, exploiting the new grazing opportunities which present themselves. This is his ex post choice.

If we solve Abel's problem recursively, i.e., through backward induction from period t = 2 to t = 1, we would take the following steps. The optimal choice of period 2 location x_2 is given by the maximand of a function f representing "ex post utility." (The function f is assumed to be strictly concave in its arguments.) We postulate that this choice of period 2 location will in general depend on his period 1 location, the period 2 rainfall, and the property rights regime in place. Nomadic nonexclusive property rights are defined as property rights that secure the profit stream of the livestock production activity wherever such production takes place. In other words, the establishment of nomadic property rights guarantees Abel the full profits of spatial flexibility. The location of production activities in period 1 can differ from the location in period 2. Thus, Abel's problem in period 2 is the following:

$$\max_{x_2} f(x_1, x_2, e, Z) \qquad (1)$$

x_1 = location at time t = 1

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[4](...continued)
The first and second moments are:

$$E(\mathbf{e}) = \alpha/\beta$$
$$Var(\mathbf{e}) = \alpha/\beta^2$$

For the particular simulation a pattern which was linear in E(**e**) and Var(**e**) with respect to movements along the North-South axis was chosen. Appendix Table 1 presents the parameters used for the simulation.

x_2 = location at time t = 2

Locations are defined as vectors of location coordinates of the grid map.

e = rainfall distribution in period 2: not known at t=1, but known at t=2.

Z = variable representing property rights. If Z=0, property rights are non-exclusive. Such rights allow Abel to change location in period 2. If Z=1, exclusive property rights exist which prevent locational mobility.

The above optimization problem yields the optimal period 2 location:

$$x_2^* = x_2^* \,(x_1\,,\, e,\, Z) \tag{2}$$

Now think about Abel's problem in period 1. Abel has observed rainfall in period 1 and has moved to the optimal location x_1. Next he needs to consider moving from x_1 to x_2. The primary question he asks himself is whether he should establish non-exclusive rights Z=0 to a particular location while recognizing that information gathering and contracting associated with movement of his herd may not be costless. In other words, transactions costs must be considered.

Thus, the choice of location is based on Abel's subjective expectations with respect to rainfall distributions and the profits and costs incurred through relocation to x_2 after a particular rainfall. Optimal locations x_1 and x_2 are governed by the following dynamic programming problem:

$$\underset{x_1}{\text{Max}}\ E_1\{\underset{x_2}{\text{Max}}\ f(x_1,\, x_2,\, e,\, \delta,\, Z)\} \tag{3}$$

where E_1 is the expectations operator in period t = 1 over the random variable e, and δ represents a transaction cost parameter associated with movements.[5] Figure 2 compares the ex post utility obtained under three

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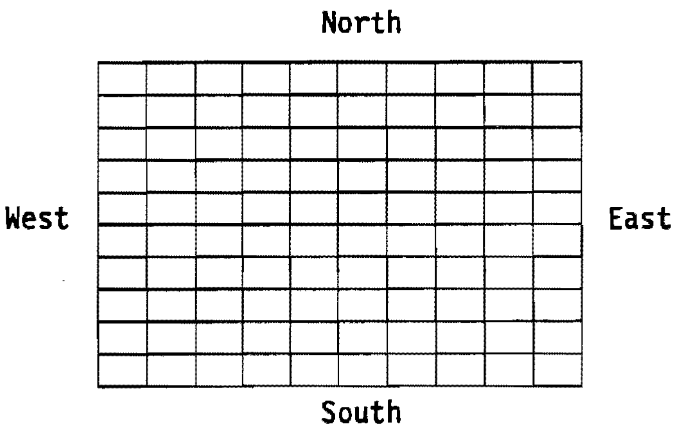
[5] The transactions costs associated with mobility are assumed to take the following form:

$TC = \delta\,|x_2 - x_1|$
TC = transactions costs
δ = transactions cost parameter.

Figure 1 – Locational Grid and Stylized Sahelian Rainfall Distribution

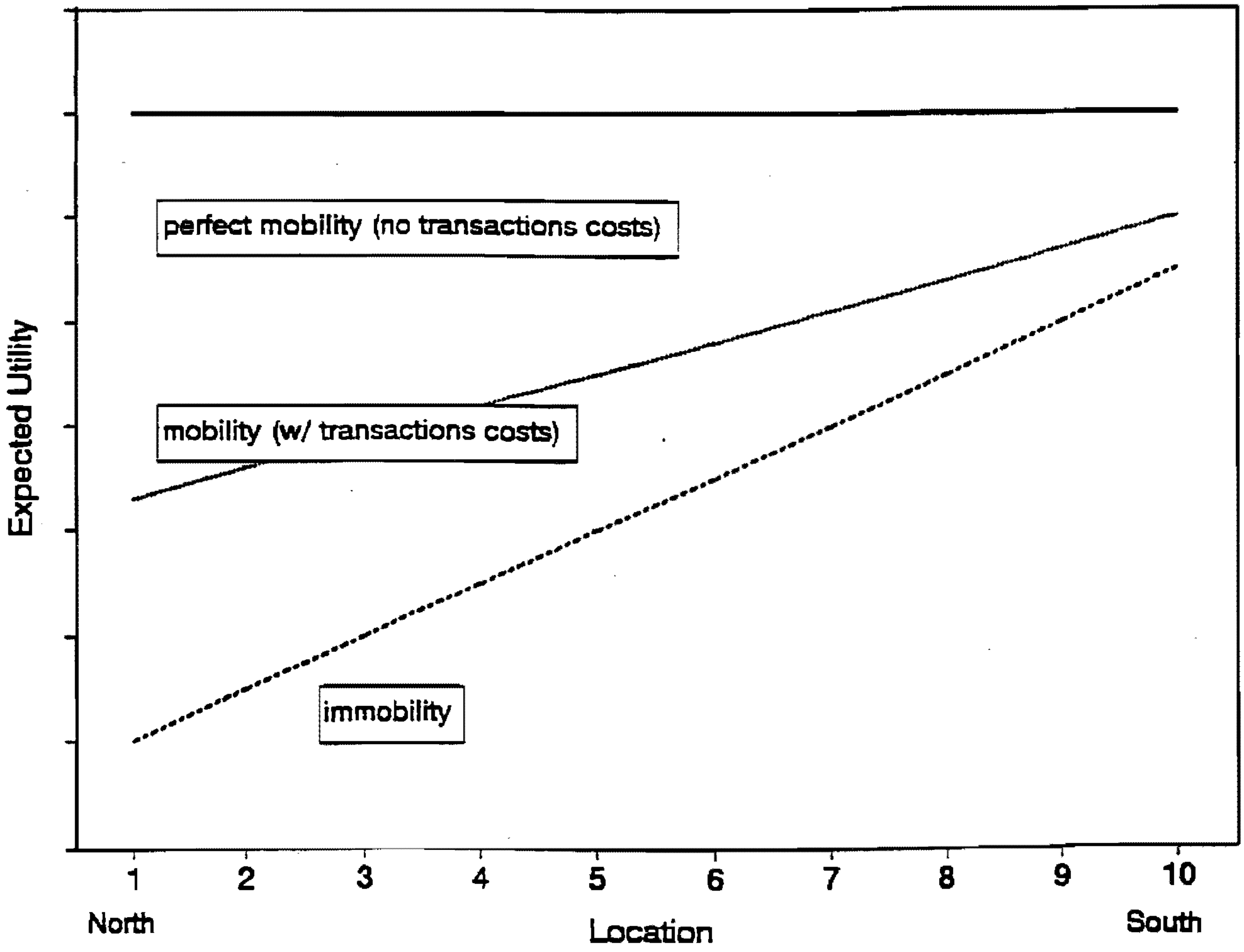
E(e)	C.V.
100	1.00
500	0.16
1000	0.05



Note: E(e) denotes the mean rainfall e, while C.V. denotes its coefficient of variation:

$$\frac{\sqrt{Var(e)}}{E(e)}$$

Figure 2 – Expected Utility of Abel – A Nomad



alternatives.[6] The first alternative assumes perfect mobility. The second alternative has transaction costs imposed on mobility. The third alternative–"immobility"–assumes that Abel stays on the same location during both periods. Abel's potential period 1 locations are projected in terms of a north-south dimension only. Obviously, if movements are costless, a fully mobile Abel does not have an a priori preference for a given location. Utility under this regime is graphed as the solid line. If transactions costs on movement are imposed, the expected utility is reduced and a southern location becomes more desirable. The expected value of utility if Abel remains on his period 1 location, i.e., under an immobile production technique, are indicated by the lowest dotted line in Figure 2. As a result, Abel would want to move south, given the higher expected value of rainfall and lesser variance there. At some point, Abel might even prefer to settle in the south and establish himself as a rancher with a fixed location.

Property rights that allow Abel to secure the benefits derived from a strategy based on "flexible response" to environmental variability represent economic value. Such property rights secure the full income stream from a mobile production technique. They secure production profits in both periods and allow for movement from period 1 to period 2 location.

In general, the value of flexibility F (measured in utils) is given by:

$$F = \max_{x_1} E_1\{\max_{x_2} f(x_1, x_2, e, \delta, Z)\} - \max_{x_1=x_2} E_1\{f(x_1, x_2, e, \delta, Z)\} \geq 0 \qquad (4)$$

The nonexclusive property rights regime ($Z = 0$) permits Abel to secure the full benefits of flexibility. The value of this economic institution is derived from the value of ex post flexibility F. Abel assesses the value of nonexclusive nomadic property rights by comparing the result of the maximization problem under full mobility with the result of a maximization problem under which he would not have any mobility. The absence of such nomadic rights would constrain Abel's choice of x_1 to be equal to x_2. If exclusive property rights exist, i.e., $Z = 1$, then $x_1 = x_2$, and it can be shown that $F = 0$.

Abel can now calculate the expected value of flexibility with and without transactions costs. The results appear in Figure 3. The solid

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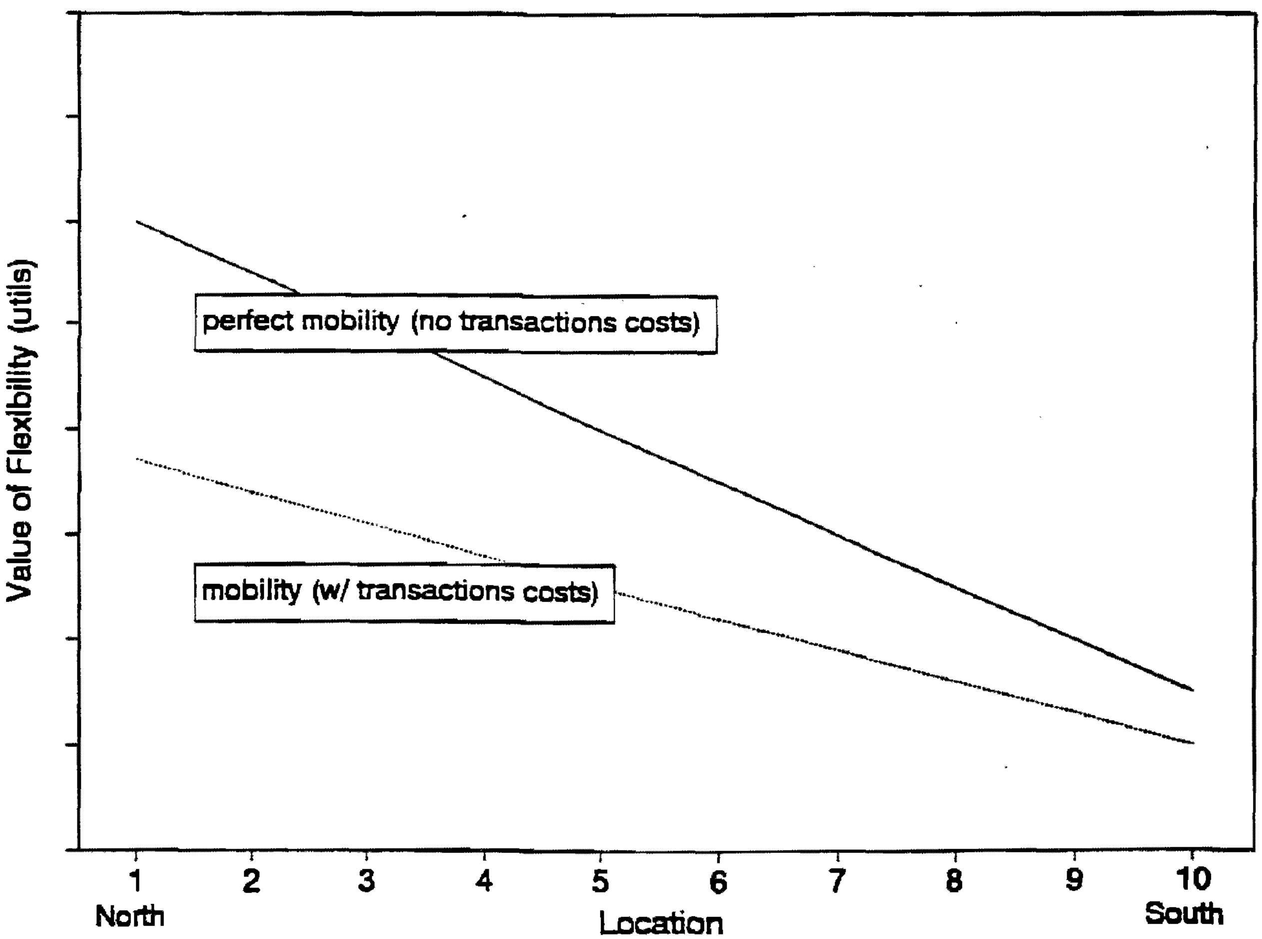
[6] Given a certain period 1 location, the expected value of the ex post utility function was numerically calculated by an iterative simulation method. The specification of the utility function is given in the Appendix. Many of the results presented below will hold *irrespective* of risk preferences.

Figure 3 – Value of Flexibility



line represents the value of flexibility without transactions costs, while the dotted line represents its value with transactions cost taken into account. As expected, the value of flexibility is highest in the North and lowest in the South. The introduction of transactions costs lowers the value of flexibility for every point of the grid.

What would be Abel's maximum willingness to pay for a nomadic property regime, which, after all, is not costless to uphold? If we assume that we can express the economic problem into monetary values, we can introduce initial wealth w. Abel's willingness to pay for nonexclusive property rights Z = 0 would be implicitly defined by the following equation:

$$\max_{x_1} E_1\{\max_{x_2} f(w - WTP, x_1, x_2, e, \delta, Z = 0)\} = \qquad (5)$$

$$\max_{x_1=x_2} E_1\{\max f(w, x_1, x_2, e, \delta, Z = 1)\}$$

w = initial wealth
WTP = Willingness to Pay

This equation gives an implicit definition of Abel's willingness to pay for property regime Z = 0. If his willingness to pay is positive, Abel will demand nonexclusive property rights, i.e., Z = 0. The willingness to pay for such a property regime will in general increase with the value of flexibility. As was shown in Figure 3, the value of flexibility is highest in the north. Extreme rainfall variability increases the value of an adaptive strategy vis-à-vis a nonadaptive strategy, and, thus, the likelihood that a nonexclusive property rights regime would be established.

Whereas the optimal domain of such a regime in our model is in the north, its territory, i.e., a particular set of ex post locations, is not *a priori* defined. Only *ex post* movement following a particular realization of the random rainfall variable will define actual territorial occupation.

We have shown that Abel's production technique induces a demand for property rights that enable him to capture the benefits of flexibility. The base comparison of expected utility (with or without transactions costs) was always with a situation in which his pastoralist activity was restrained by immobility. For Cain, the farmer, the problem is different. Being a farmer, Cain makes the *ex ante* choice of location for the two periods. By definition, he does not move his farm around between the two periods. We assume that Cain's technology—sedentary farming—is not feasible in the arid north (i.e., above the northern cultivation limit). Furthermore, we assume that, as one moves south, comparative advantage gradually shifts from pastoralism to farming. In other words, one will reach a location where Cain's expected utility becomes strictly higher than that of an immobile Abel.

Cain's maximization problem is defined as:

$$\max_{x_1=x_2} E_1\{g(x_1, x_2, e, \delta, Z)\} \tag{6}$$

Cain's choice of property regime is also derived from a comparison between two maximization problems. Cain compares expected utility of crop production under an exclusive property rights regime with the expected utility of sedentary livestock production. Thus, we assume that initially Cain is a sedentary pastoralist, who ponders whether he should switch production technology, given the ecosystem in which he finds himself. In making this choice, Cain realizes that he will have to secure the benefits of crop production by establishing exclusive property rights to the location. For instance, Cain will need to protect his crops against possible incursions of Abel's herds. Such exclusive cultivation rights are indicated by the variable $Z = 1$. Introducing initial wealth **w**, Cain's willingness to pay for an exclusive property rights regime will implicitly be given by the following equation:

$$\max_{x_1=x_2} E_1\{g(w - WTP, x_1, x_2, e, \delta, Z = 1)\} = \max_{x_1=x_2} E_1\{f(w, x_1, x_2, e, \delta, Z = 0)\} \tag{7}$$

If, for a given location, Cain's willingness to pay is greater than zero, he will demand an exclusive cultivation property right $Z = 1$.

Given the above model, it is now possible to endogenize the choice of technique and property rights regime given the rainfall probability distribution of a particular location. Ruling out the settlement of conflicting claims by fratricide, we could evaluate for each location x the maximum willingness to pay of each individual. The property rights regime governing the location will then depend on whether the WTP of Abel is greater than, equal to, or smaller than the WTP of Cain. We know that for Abel an adaptive strategy performs always at least as well as a non-adaptive strategy:

$$\max_{x_1} E_1\{\max_{x_2} f(x_1, x_2, e, \delta, Z=0)\} \geq \max_{x_1=x_2} E_1\{f(x_1, x_2, e, \delta, Z=0)\} \tag{8}$$

However, we do not know a priori for a given grid on the map:

$$\max_{x_1=x_2} E_1\{f(x_1, x_2, e, \delta, Z=0)\} \geq \leq \max_{x_1=x_2} E_1\{g(x_1, x_2, e, \delta, Z=1)\} \tag{9}$$

And thus, we are unable to sign a priori

$$\max_{x_1} E_1\{\max_{x_2} f(x_1, x_2, e, \delta, Z=0)\} \geq \leq \max_{x_1=x_2} E_1\{g(x_1, x_2, e, \delta, Z=1)\} \tag{10}$$

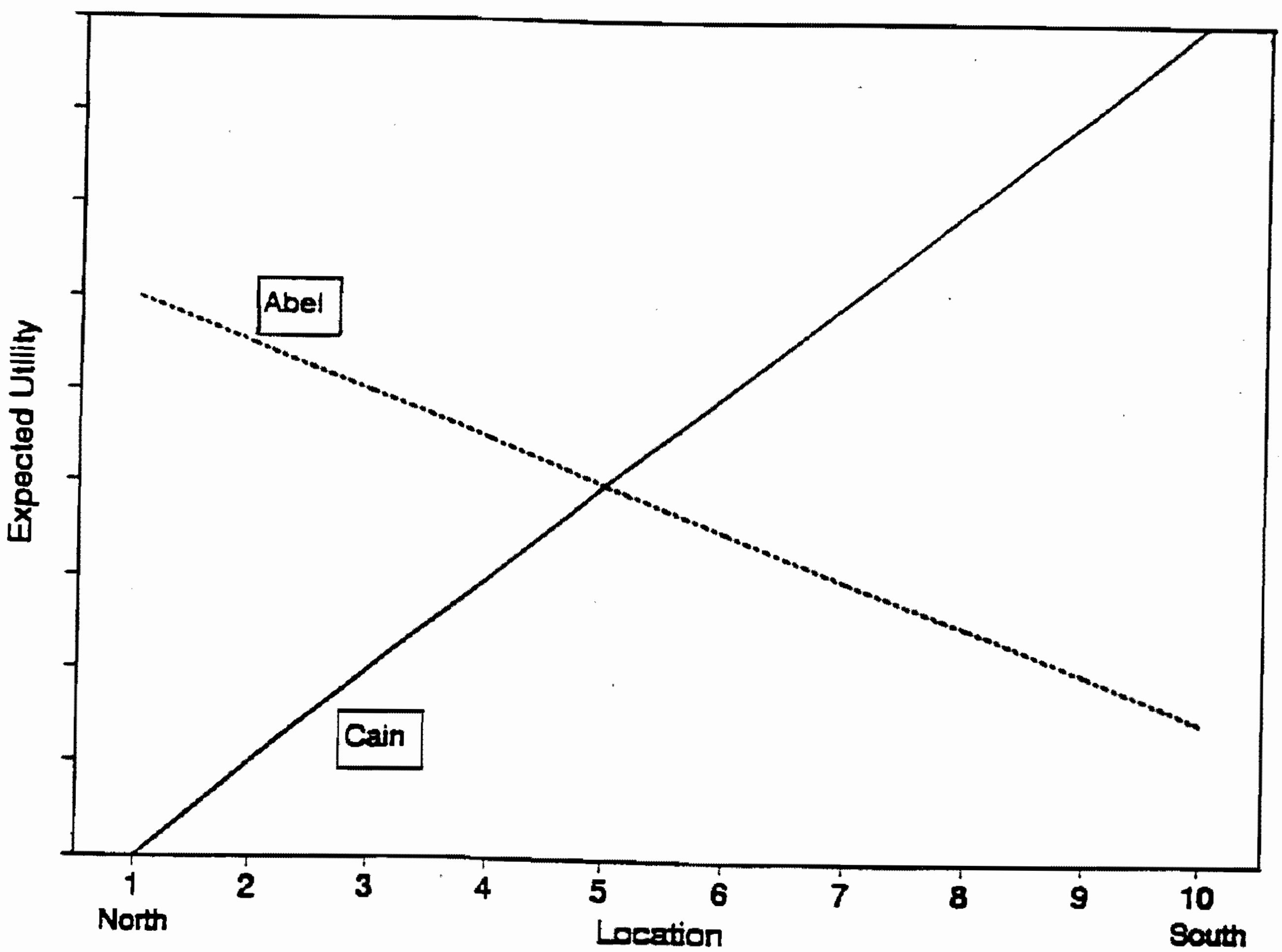
The sign of the above inequality for a given location determines its optimal production technique and property rights regime (see Figure 4).

By comparing two different maximization problems, both Cain and Abel choose the optimal property rights regime; choice of economic institution is endogenized. The equilibrium point will be that point for which the two equations are equal.

The area to the north of the equilibrium point will be the optimal domain for livestock production and fall under Abel's nonexclusive nomadic property rights. The area to the south, *ceteris paribus*, will be the optimal domain for crop production governed by Cain's exclusive cultivation property rights. The domain of Abel's technology—with technology defined as the combination of the optimal technique and the appropriate property right—does not imply "exclusive territory." For Cain's technology, however, "domain" does imply territorial exclusivity. The choice of technology in the model is made given period 1 location. In period 2, then, Abel's mobility may very well lead him into Cain's domain.

How would an increase in demographic pressure affect Abel's choice of property rights regime? Note that each additional Cain—each additional grid under exclusive property—lowers the value of flexibility for Abel. By the dualistic nature of the model, demographic pressure would directly lead to an increase of Cain's domain under exclusive property rights, given the reduction of Abel's willingness to pay for nonexclusive property rights. In other words, an exogenous increase of the farming population lowers the value of Abel's adaptive strategy and, consequently, his willingness to pay for nonexclusive property rights.

Figure 4 — Cain and Abel



4. POLICY ISSUES

The political history of the West African savannah has been characterized by profound shifts in the balance of power between pastoralists and farmers. Some of these shifts have resulted in the annulment of the property rights of pastoralists. Others have been associated with the imposition of considerably increased transaction costs on the operation of the pastoralist production system.

Foremost, the transaction costs imposed on the pastoralist production system increased because of the decline of political influence of the pastoralist population. During the 18th and 19th centuries, pastoralists colonized large portions of the West African savannah through an imperialist expansion strategy based predominantly on professional warfare. This system rested on the mobilization of large armies of slaves, on the mobility of cavalries (which explains why the invasions stopped short of the tse-tse fly infected forest zones) and on the effective control over tribute-paying farming populations, some of which were held under a system of slavery (see, e.g., Bah 1986; Franke and Chasin 1980). The incorporation of sedentary farming populations in the nomadic political economy seemed to have been a structural element of the economic strategies pursued by nomads (Lovejoy and Baier 1976; Konczacki 1978).[7] Especially in terms of drought, the nomads could fall back upon the food base provided by the farmers in the south. In some cases, such transfers were not part of a formal political economy, but part of a pattern of opportunistic raids of nomads into the southern farming zones. In other cases, the relationship between pastoralists and farmers was more symbiotic (Baier 1976; Mortimore 1989; Forde 1960).

The French colonizers attempted to pacify the region through the sedentarization of the nomads and the abolition of slavery. Policies of *divide et impera* were employed to reduce the political power of the nomads, but at times the attacks on the nomadic hegemonies, such as the 1917 massacre of the nomadic aristocracy at Tanut in Niger (Lainé 1982) were direct and brutal. The nomadic political power base eroded quickly, while direct and indirect taxation policies resulted in severe restrictions on the wider economic exchange with the southern regions.

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[7] At the same time pastoralist mobility was the basis for the development of various long-range trading networks: The caravan trade across the Sahara with the Mediterranean region and the sub-Saharan trade with the southern savannah and forest zones of West Africa.

The nomadic empires collapsed when the upkeep of the slave economy became infeasible and feudal taxation revenues dwindled.

Even now, the relationship between the nomadic tribes and the sedentary farming populations is often an uneasy one, compromised by its rather turbulent history. Nomads are often seen as strangers, transients, and noncitizens with no legitimate claim to property rights or natural resources. The effect of this persistent "farmer bias" is that changes in property rights regimes introduced by the colonial and postcolonial states often completely annulled pastoralist property rights. Nomads were simply expropriated by the declaration that all *terres libres*, or free lands, (most of which are, in fact, grazing lands) were to be considered national property.[8] In fact, a typical legal assertion is that the "nation" owns all the land and that therefore the nomads have to compensate the "nation" for use of the grass. This compensation rule is used to justify the considerable taxes levied on pastoralists. Interestingly, this reasoning is conspicuously absent with respect to taxation of cultivation or fuel wood collection by farmers.

In the semiarid tropics, an increase in population pressure does not necessarily lead to a "Boserupian" process of intensification (see Boserup 1965). Population pressure may find relief only by extending production, pushing cultivation onto marginal lands. Under such circumstances farmers expect to get into increased competition with nomads. These expectations induce a phenomenon known as "preventive" clearing. Both nomads and farmers recognize the principle of usufructuary property rights. When the nomads are absent, farmers "preventively" clear land in order to secure property rights. Upon their return, the nomads are confronted with a *fait accompli*. Such a preventive assertion of property rights by farmers is often backed by formal legislation. For instance, the agrarian reform, introduced in Niger in 1977, specified that fields left fallow for more than nine years were considered "free." The result of this legal reform was an increased insecurity over the status of fallow lands. Consequently, farmers reduced fallow periods and embarked upon strategies of "preventive" clearing.

Accelerated environmental degradation and an intensification of conflicts between nomads and farmers were the results (Thompson 1982).

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[8] Even in the rare cases where legislation seemed to favor pastoralist property rights, the de facto enforcement usually favored the farmers. Thus, in Niger, all lands north of the cultivation limit (approximate latitude 15° 10' north) were officially declared pastoralist zones. However, this legal restriction did not prevent farmers from entering these areas in the 1960s. They were:

> ...effectively supported by government administrators apparently unwilling to carry out the legal restrictions on the northern limits to cultivation (Franke and Chasin 1980, 98).

Land once used for grazing was increasingly cultivated for production of cash crops. Such was the case in Niger where "...peanut cultivation in the 1960s began to spread north of its previous boundaries, into regions that brought peanut farmers into direct competition with pastoralists" (Frank and Chasin 1980, 96). Additionally, the location of new agricultural projects, especially large irrigation projects, further constrained trek routes. Irrigation schemes typically occupy large areas of valley bottom lands, which constitute crucial pastoral resources especially during the dry season. Dry-season irrigation of these valley-bottom lands cuts nomads off from such resources and may upset trekking routes in a major way.

Even government policies that purported to benefit the development of pastoralists often merely attempted their sedentarization in areas where sedentarization was not feasible:

> The uncertain nature of agriculture north of the 300 mm isohyet, and the low productivity of the soil, forced the settling nomad to retain his flock as a secondary source of livelihood. As a rule, the new settlements were formed either around the government posts, established at watering points, or around "family wells." Overstocking and consequent overgrazing led to a decline in the quality of animals (Konczacki 1978, 59).[9]

State-sponsored introduction of new technology usually has also had dubious effects. Vaccination campaigns led to larger herds, but of a poorer quality, because of a decrease in natural selection and an increase in overgrazing (Crotty 1980, 129). Deep tube wells opened up areas previously too arid for grazing. Local pastoralists did not obtain property rights to these wells, whereas new immigrants were attracted by the wells, but refused to abide by the rules of the original property regime. The "bore-hole paradox" was born: before the introduction of bore holes, shortage of water precluded degradation of the grasslands, while access to water was regulated. After the introduction of bore holes, grazing could continue for longer periods, while access to water was deregulated and became effectively "open access." At the same time, herd sizes increased through an increase in labor productivity: less labor was now necessary to water the animals (Konczacki 1978; Crotty 1980). The combined effects resulted in overgrazing of the areas in the vicinity of these wells (e.g., Kintz 1982).

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[9] For East Africa, Hogg (1987) shows that sedentarization of nomads around an irrigation scheme had detrimental ecological effects. Moreover, the pastoralists who were settled closest to the center of an irrigation scheme eventually ended up the poorest, while the pastoralists on the fringes of the scheme were able to increase their wealth through a combination of access to the irrigation scheme and continued access to the grazing areas on the fringes and outside of the scheme.

Other popular livestock sector projects included the establishment of ranches. The development of ranching assumes that the local ecosystem is capable of supporting herds year-round when these herds are confined to a specific territory, i.e., a fenced-off ranch. This is precisely the suboptimal strategy that the pastoralist production system of the Sahel attempts to avoid. The limitations of the ecosystem to support cattle on a permanent basis caused many ranching projects to resort to additional feed inputs, for instance by importing grain from more southern regions. Crotty (1980, 133) commented:

> Fattening cattle on grain in Africa, where per caput grain availability is half the world average and pastureland availability is two and a half times the world average...lacked common sense. It was a nonsense.

Other ranching projects attempted to obtain supplemental feeding from the by-products of certain agro-processing industries (e.g., cotton mills, sugar cane processing factories, beer industries). However, for various reasons of cost-effectiveness, the optimal location of such industries is typically close to urban centers. To establish ranching schemes in the vicinity of major urban centers carries high opportunity costs with respect to land use. Alternatively, transportation of the above by-products to regions more suited for pastoral production is prohibitively expensive.

The "integration" of crop and livestock production has also been emphasized as a preferred agricultural policy. However, given the agro-climatic constraints on intensification with respect to crop as well as livestock production in the semiarid tropics, the importance of integration of livestock and crop production on the farm level—the key factor in the transformation of European agriculture—has been largely overstated (Breman and De Wit 1983). The integration of farming and livestock production at the farm level is often constrained by unfavorable combinations of agro-climate, soil conditions, population density, and labor demands (Delgado 1979). For instance, the potential to keep livestock year-round on the farm—the potential for sedentary mixed farming—is severely limited by natural fodder supply per unit of land in the Sahelian and northern Sudanian regions. Moreover, while potential fodder supply per acre increases towards the south, opportunity costs of fodder production also increase because of the increase in land scarcity.

However, above the farm level, the regional environment within which the wider agro-pastoral production system operates offers several opportunities for economic exchange through the exploitation of the comparative advantages held by the different technologies in their respective agro-climatic zones. Various types of contracting, other than commercial exchange of outputs, have evolved to capture the benefits of such exchange opportunities (Bromley and Chavas 1989). The widespread phenomenon of farmers renting their cattle to nomads under a variant of the sharecropping contract is a good example of an economic exchange based on such comparative advantages. The nomad herds the farmer's cattle in exchange for a share of the outputs, usually specified in terms of calves and/or milk. Informational and incentive problems are reduced under such sharecropping contracts. Farmers profit from such diversification of their asset portfolio across ecological zones, while nomads profit from the increased access to capital. Such investment opportunities are also highly valued by urban investors (Kintz 1982). Another common type of contract is known as the *contrat de fumure*, under which a farmer allows the nomad to graze cattle on the crop stubbles left after the harvest, when the animals can no longer damage the crops, in exchange for the benefits of animal manure. Note that both contracts explicitly avoid the risk of negative externalities between cultivation and herding activities. Under the rental agreement, grazing cattle do not interfere with cultivation since the farmer gives cattle to the herder who takes them along on his transhumant movements. The *contrat de fumure* properly demonstrates that exclusive cultivation property rights need not be defined for a whole year; they only need to be secured for the duration of the growing season (Dahlman 1989; Wade 1986). Outside of the growing season, both farmer and nomad benefit from the establishment of a different set of property rights.

Given all the above factors, then, there has been a marked increase of conflicts between nomads and farmers, generally at the expense of the nomads. In particular, what has been called the "colonization" of the Sahel by the farming population greatly reduced the spatial flexibility on which the pastoralist technology was based. Nomads had to circumvent larger cultivated areas, lengthening their routes and increasing the costs of operating the pastoralist system considerably.[10] At the same time, however, the Sahelian livestock production system saw the demand for its product increase and reacted by a continuous increase in supply. Population growth in the wider West African region increased the price of meat relative to labor. As a result, the nomads increasingly specialized in cattle production and the Sahelian herd grew steadily further adding to the tensions between nomads and farmers (Konczacki 1978; Crotty 1980). Moreover, the increased profitability of livestock activities induced more and more farmers to invest in herds of their own. These herds were not always given in custody to the nomads following the traditional institutions. Thus emerged new contenders for water and grass with no linkage to the pastoralist regulatory mechanisms.

The positive supply-response apparently offset the reduction in the spatio-temporal flexibility of the nomadic system. Rather, reduced flexibility increased livestock losses during periods of extreme environmental variability, such as the prolonged drought period of 1968-1976. At the height of the drought, in 1973, losses were estimated at 20

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[10] For instance, movements further south often led to increased taxation by the different farming populations along the way. See also Grégoire 1982b.

to 70 percent, depending on the source (Konczacki 1978). Although some losses might have been exaggerated, the general consensus is that the capacity of the nomadic system to manage the effects of the drought was greatly reduced, compared with earlier droughts such as the one in 1930 (Grégoire 1982a). More importantly, perhaps, increases in herd size may have been a combined response to relative prices and to the reduction of flexibility of the pastoralist system. Several authors have argued that a large herd size *per se* can function as a risk-reducing strategy. It constitutes an insurance in times of excessive mortality induced by drought (Monod 1975; Van Raay 1974; Sanford 1982). However, such strategies should be considered suboptimal to flexibility-based strategies.

In line with the theoretical arguments made above, a reduction in the value of flexibility may also induce the sedentarization of nomads. Such an apparently spontaneous transition from specialized herding to farming, however, need not be interpreted as an optimal evolution but may represent a constrained and impoverishing response (Smith 1978; McCown, Haaland, and de Haan 1979). Such processes of suboptimal sedentarization often have ecologically harmful effects.

Nomadic property regimes allow pastoralists to implement adaptive strategies to environmental uncertainty. A typical nomadic property regime defines a set of property rights, such as rights of passage, grazing, and watering. Historically, such rights, are typically established under common property regimes that regulate and coordinate grazing, watering, trekking, information gathering, and contracting vis-à-vis other nomads and sedentary farmers. An adaptive strategy and its associated property rights regime generally require ex post coordination between economic actors. By contrast, a nonadaptive strategy typically requires only ex ante coordination. From an economic point of view, then, the informational requirements of adaptive strategies may directly induce the establishment of a common property regime if coordination between individuals is less costly under centralized management at the group level than under a system of private contracting between independent actors.

Interestingly, some of the more recent pastoral policies attempt to restore indigenous common property regimes by creating exclusive pastoral zones. "Territorialization" of pastoralists has been advocated by a number of observers (see Adams 1975; Gallais 1979). However, typical pastoral property regimes were not defined in terms of a specific territory. In fact, property regimes—in line with the economic theory that we outlined above—enabled continual mobility without restricting nomadic groups to a particular zone. The delimitation of pastoral zones or the establishment of "group ranches" under territorially exclusive property regimes, then, does not constitute an appropriate policy for resource use in the semiarid tropics. Empirically, such policies have often been associated with overuse of the resource base, amplification of negative effects of drought periods, and increased conflicts between nomads and farmers, among nomadic groups, and within nomadic groups (de

Hann 1990; Little 1987; Mortimore 1989). Moreover, such policies sometimes end up allocating exclusive grazing rights to groups of sedentary farmers (Grégoire 1982a).

As was argued above, adaptive strategies imply a need for continual coordination among actors. The informational requirements for such coordination at local levels are probably more efficiently met by the establishment of decentralized property regimes than by attempts at coordination through centralist intervention by the state. Legislation that accords a legal monopoly with respect to pastoral issues to a centralist state may only result in even more ambiguity and insecurity at all levels (local, national, and international), rather than in the intended tenure security. The role of the state, then, seems to emerge at two levels: at the local level, the state should facilitate the creation of property regimes that would reduce the transaction costs of pastoral strategies. At the national and international level, the state can intervene more directly. First, the state can assist the pastoralist production and marketing system when it requires mediation for movements over longer distances. Such mediation is especially important during drought years. Secondly, the West African states can considerably reduce production and marketing transaction costs by creating a uniform administrative and taxation system. Even if the total tax load is not reduced, any reduction in the mere number of different taxes and bureaucratic requirements would significantly reduce transaction costs. Uniform international legislation would ideally be enacted. Given the nature of the economic problem, efficient and equitable institutional solutions can only arise from negotiations among all actors involved. The framework within which such negotiations should take place is necessarily local, national, and international at the same time (Mortimore 1989). Such negotiations may very well open a Pandora's box of political conflicts. An integrated and negotiated attempt at conflict mediation and the definition of property rights, however, may be preferable to the existing situation characterized by a continual flaring up of conflicts.

5. CONCLUSIONS

The analysis has demonstrated the importance of flexibility as an optimal strategic response of individuals faced with input uncertainty. Empirically, the optimality of spatio-temporal flexibility as a strategic response by pastoral nomads to environmental uncertainty has been recognized by many observers. However, the relation between optimal techniques and the emergence of property rights that capture the benefits of such techniques has generally been less well understood.

The model we used stresses the interrelationship between the choice of technique, the emergence of specific property rights, and the resulting resource allocation as a function of environmental variability. A dual economy arises as the result of rational choice by individuals. Such rational choice includes the choice of optimal property rights regimes, which capture the income streams of techniques appropriate for a particular agro-climate. The model can be seen as an application of the property rights theory developed by Demsetz (1967) and others. However, the model does *not* conclude that exclusive private property rights in land, e.g., "absolute ownership of land," are necessarily optimal. Given a spatio-temporal characterization of risk, other types of property rights may be more appropriate. Overexploitation of natural resources in the Sahel has often been associated with the introduction of techniques that allowed for a more intensive use of a given range without the formulation of property rights regimes that could regulate and coordinate such use.

Moreover, the duality of the economy in our model does not give rise to a dual sector based on territorial duality. Nonexclusive property rights do not attempt to internalize the benefits of exclusive territorial property. They internalize the benefits of spatio-temporal adaptive strategies. Such "flexible response" property rights stress the property relation of the individual vis-à-vis other individuals rather than the property relation of the individual vis-à-vis a particular territory. Property rights emphasize rights and duties of the individual vis-à-vis other individuals: the territorially flexible property rights of the nomad are no less property rights than the "Cartesian" and territorially inflexible property rights of the farmer.

The West African Sahel exhibits several characteristics that have amplified the negative effects of a reduction of flexibility of adaptive strategies on which the indigenous pastoralist property regimes were based. Any reduction in the system's flexibility carries a demonstrable economic cost. Such costs can rise dramatically during a prolonged drought, which is a common, naturally occurring phenomenon in semiarid and arid regions. As was shown for the Sahel, such constraints on economic strategy have been detrimental to man, animal, and environment. While government policies with respect to the livestock sector seemed either ineffective or inappropriate, conflicts between nomads and farmers became steadily more frequent, and herd movements became increasingly restricted. In other words, although the need for economic coordination increased during the period under consideration, the transaction costs associated with such coordination were shifted towards the pastoralists.

Abel's problem was to explain to Cain that if the latter would claim "absolute" exclusive property rights, both would be worse off. In other words, Abel attempted to prevent a Pareto-inferior outcome. We have argued that the prevention of such a Pareto-inferior outcome should also be the focus of current development policies with respect to the agro-pastoral production systems of the West African Sahel. Policies should, first, acknowledge the structurally different techniques that underlie the agricultural and pastoral systems, respectively. Second, this recognition should then lead to the formulation of policies that would further the establishment of an institutional setting within which both sectors could be accommodated. In particular, the acknowledgement of the structural differences in production techniques should have direct implications for the formulation of optimal property rights regimes.

Without a fundamental change in development policies for the Sahel, then, the gloomy scenario of Cain and Abel may be brought to its ultimate conclusion. Myth and reality have already become dangerously close in the recent history of the region. The recent "wars between brethren" (viz. the violent conflicts between Mauritania and Senegal and between Mali and Burkina Faso) were directly linked to the herder/farmer problem and may serve as ominous examples.

APPENDIX

SIMULATION SCENARIO

Both Cain and Abel derive utility U from revenues π, with π being a function f of rainfall e. Rainfall is simulated as in Appendix Table 1. In particular, in each year i, Abel's utility is defined as:

$$U_i = A*\ln(\pi_i + C) \tag{11}$$

$$\pi_i = e_i$$

$$A,C = \text{constants}$$

And for Cain:

$$U_i = B*\ln((\pi_i + C) - D \tag{12}$$

$$\pi_i = e_i$$

$$B,D = \text{constants} \quad B>A,\ D>0$$

The logarithmic specification of the utility function is not crucial to the analysis. All results will hold irrespective of risk preferences.

A PERFECTLY MOBILE ABEL

In each period, Abel observes the rainfall in the region. For each location he calculates the ex post utility if he were to move his herd there.

$$U_i = A*\ln(e_i + C) \tag{13}$$

with e_i the observed rainfall in period i.

Abel establishes a ranking of all grids in terms of profitability and, since movements are costless, he moves to the grid with the highest profits. Given his choice of location in period 1, Abel can numerically calculate the expected value of utility for each grid for period 2. In the simulation model, such calculation was iterated 50 times. In each iteration, each location received a new random draw from the specific rainfall distribution associated with its grid. Abel ranks the grids in terms of utility and moves to the highest one. Expected utility is the

Appendix Table 1 – Simulated Rainfall Pattern Using Gamma Distributions

Location	E(e)	Var(e)	Std	C.V.	α	$1/\beta$
1 (North)	100	10,000	100.00	1.00	1.00	100.00
2	200	9,167	95.74	0.48	4.36	45.83
3	300	8,333	91.29	0.30	10.80	27.78
4	400	7,500	86.60	0.22	21.33	18.75
5	500	6,667	81.65	0.16	37.50	13.33
6	600	5,833	76.38	0.13	61.71	9.72
7	700	5,000	70.71	0.10	98.00	7.14
8	800	4,167	64.55	0.08	153.60	5.21
9	900	3,333	57.74	0.06	243.00	3.70
10 (South)	1,000	2,500	50.00	0.05	400.00	2.50

Notes: Std = standard deviation
C.V. = coefficient of variation
units of e = millimeters

simple average calculated over the 50 iterations. At the same time, utility for period 1 location in period 2 was calculated to arrive at the utility under immobility. Additionally, transactions costs (see below) on mobility are imposed. Results are shown in Figure 2. The value of flexibility (in utils) is presented in Figure 3.

TRANSACTIONS COSTS

Transactions costs C are associated with trekking from the period 1 location to the period 2 location. These costs are assumed to vary linearly with distance. If each location for a given period i can be characterized in terms of x- and y-coordinates (x_i, y_i), the transactions cost function is given by:

$$C(Z=0) = \delta(|x_2 - x_1| + |y_2 - y_1|) \qquad (14)$$

$\delta = 100$

Z = variable representing property rights. Z=0 implies the existence of nonexclusive property rights.

The transactions costs parameter δ transforms distance into costs and describes the general political and economic environment the pastoralist Abel finds himself in. The higher δ, the more costly pastoral movements are. Abel's utility in period 2, then, consists of period 2 revenues minus the costs for movement from period 1 location to period 2 location. The introduction of transaction costs affects the ranking of the grids in terms of utility. Some locations may have high rainfall but are too far removed. The same numerical evaluation of the expected profits for a given location was undertaken as in Case 1. Results are graphed in Figure 2.

CAIN

Cain's utility function is a linear transformation of Abel's utility function in a situation in which Abel would be restricted to one location. This transformed curve has a lower intercept, but a higher slope. These assumptions are graphed in Figure 4.

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