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Agricultural science and technology policy in Africa

S.W. Omamo [a,*], J.K. Lynam [b,1]

[a] *International Food Policy Research Institute, 2033 K Street NW, Washington, DC 2006-1002, USA*
[b] *Rockefeller Foundation, Box 47543, Nairobi, Kenya*

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Abstract

This paper addresses the central problem facing agricultural policy makers in Africa today, namely, how to promote self-sustaining processes of growth fueled by technological advances, concentrating on small-scale agricultural production and trade. At bottom, the argument is an epistemological one, but with several practical implications. The dominant theoretical perspective on technical change and innovation in small-scale agriculture (choice under constrained maximization) is argued to be highly effective in identifying problems with small-scale agriculture. But its reliance on equilibrium notions renders it silent on solutions, i.e. each component of an equilibrium affirms the others, very often none more or less critically than the rest. Left vague are the processes through which the low-level technologies that purportedly underpin small-scale agriculture's problems actually come to be chosen, time and again. An alternative view is proposed, focusing on learning, adaptation, and problem-solving. Scope is thus identified for "out-of-equilibrium" improvements in smallholder production and trading systems, with important implications for policy.

Keywords: Africa; Small-scale agriculture; Technology; Policy

> [M]arket processes are generally weak in directing the emergence and selection of radical technological discontinuities. When the process of innovation is highly exploratory, its direct responsiveness to economic signals is looser ... [and its] linkages with strictly scientific knowledge greater ... [I]nstitutional factors play a direct role, providing the necessary conditions for new scientific developments and performing as ex ante selectors of the explored technological paradigms from within a much wider set of potential ones (Dosi, 1988, p. 128).

1. Introduction

Burgeoning urban populations in Africa—and the anxious attention they are receiving in the popular press (e.g. Otieno, 2001)—mask the fact that most Africans still reside in rural areas (FAO, 2001). And like most of the world's rural dwellers, nearly all of Africa's are small-scale farmers and traders. And like most smallholders, most of Africa's are poor. And like most poverty afflicting working people, theirs springs in large part from their engaging in activities that generate little appropriable economic value beyond that which goes into meeting subsistence requirements. And like most such activities, those within small-scale agricultural production and trade in Africa rest on low rates of adoption and utilization of productivity-enhancing technologies and practices—

* Corresponding author. Tel.: +1-202-862-5697.
E-mail addresses: w.omamo@cgiar.org (S.W. Omamo), jlynam@rockfound.or.ke (J.K. Lynam).
[1] Tel.: +254-2-228061.

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such as the hybrid seeds, fertilizers, and collective organizational arrangements that featured prominently in Asia's Green Revolution. The central problem facing agricultural policy makers in Africa today thus remains the same as it was at least four decades ago (Jones, 1965), namely, how to promote self-sustaining processes of growth fueled by technological advances in small-scale agricultural production and trade.

That problem is the subject of this paper. We proceed from the premise that policy toward agricultural science and technology strongly *determines* outcomes of wider agricultural policy. This wide "reach" of agricultural science and technology policies rests on the wide spatial and institutional scope of the processes that drive agricultural innovation and diffusion. Simultaneously, these processes also *reflect* (respond to) seemingly "distant" policy initiatives. We attempt a preliminary development of arguments based on this premise, with a view to identifying potential avenues for fruitful intervention by African governments clearly lacking confidence in their abilities to achieve such long-held goals as food security based on efficient and equitable growth in agricultural incomes.

Underpinning any science and technology policy framework is a vision (theory) of technical change and innovation (Dosi, 1988; Rosenberg, 1976, 1994). We argue that the dominant theoretical perspective on technical change and innovation in small-scale agriculture (choice under constrained maximization), while powerful in several respects, is inadequate as a guide to formulating and implementing agricultural science and technology policy in the African context of highly diverse agroecological and socioeconomic conditions. Adapting a theoretical framework recently developed and applied to better understand industrial innovation in highly developed countries, we propose an alternative (but not inimical) view that focuses on learning, adaptation, and problem-solving.

The next two sections outline the two views. A formal proposition linking static micro-level efficiency in small-scale, diversified, subsistence-oriented agriculture to dynamic macro-level inefficiency summarizes the alternative view. Implications for policy of that proposition are then drawn. Broad conclusions round out the paper.

2. Constrained maximization

Many years ago, the development analyst and practitioner Guy Hunter lamented the absence of a consistent rationale for what he saw as the overriding empirical regularity in African agriculture, namely, the prominence of diversified, subsistence-oriented (DSO) production patterns on small farms (Hunter, 1973). This regularity is not unique to Africa and has received considerable attention from scholars in the intervening years. For instance, key aspects of DSO agriculture have been linked to small farmers' poor access to credit (Eswaran and Kotwal, 1986), to their desires to secure an adequate nutrition (Hazell and Norton, 1986), to their aversion to risk (Fafchamps, 1992), to absent markets for food (de Janvry et al., 1991) and insurance (Binswanger and Rosenzweig, 1986), and to high farm-to-market transport costs (Omamo, 1998a,b).

Hunter (1973) suggested that the rationale for DSO agriculture, when it emerged, would take in not only farmers' decisions on-farm, but also a range of broader factors, many of which he argued were manifest in collective (social) phenomena that occurred outside markets. Anthony et al. (1979) reached similar conclusions. However, most analyses of small-scale agriculture—including those cited above—focus on individual economic units and their behavior in markets, which through the price mechanism convey all the information required for individual decision-making and therefore coordinate all economic interaction.

The typical analysis either explicitly or implicitly imagines an agricultural household maximizing expected utility by choosing levels of goods consumed, produced, bought, and sold, applying inputs according to some given production technology, and paying transaction costs for goods traded on market at exogenously given prices. Utility maximization thus is constrained by these costs and prices, by full-income (i.e. the value of a household's time endowment, plus the value of its production, less the value of the variable inputs required in production, plus any non-wage, non-production income), by quantity balances on all inputs and outputs, and by "the production technology", as captured in a known production function (Sadoulet and de Janvry, 1995; Singh et al., 1986).

Central features of DSO agriculture are fully captured in this setting. Take the subsistence orientation.

An optimal response to high transaction costs in a market for a good in which a household is a net buyer, e.g. a staple, is greater production of the item. Conversely, high transaction costs imply reduced production of goods for which a household is a net seller, e.g. most cash-crops, where a "cash-crop" is any farm output that has a small share in household consumption expenditures and a high market value relative to marketing costs. The seemingly inefficient prominence of low-return food-crops in smallholder farming systems thus is wholly rational food import substitution by households facing high transaction costs in product markets (Omamo, 1998b). Significantly, this motive for food import substitution is quite general and does not rely on assumptions of risk-aversion. A range of *known* transaction costs are sufficient to kindle the nonseparability argued to be an essential feature of smallholder agriculture (Singh et al., 1986; Udry, 2000).

Consider diversification, for given consumption preferences and endowments, increased specialization by definition implies that the range of production items declines while that of traded goods rises. The higher are unit transaction costs in markets, the more costly are strategies to specialize in production with a view to trading for items in the consumption bundle, and thus the greater is the pressure toward domestic production of some of these items. It is therefore quite feasible that yield- and income-increasing production technologies will be rejected if they raise specialization and trade to such a degree that total transaction costs exceed the sum of the net output revenue (net of input costs and accounting for consumption) and the value of the endowment (Omamo, 1998a). Again, this motive for farm enterprise diversification is quite general. And, again, it does not rely on the presence of uncertainty for its effects but depends instead on the explicit integration of transaction costs into the household's decision problem. Trading decisions (and their attendant costs) are endogenous to household production and consumption choices. So, too, therefore, is "market failure". Under conditions of uncertainty and incomplete information, risk-averse smallholders may indeed optimally self-insure via private diversification (Bromley and Chavas, 1989). However, diversification induced by failures in insurance markets for risk-averse farmers is but one manifestation of a more general phenomenon in which market failure means that benefits to self-provision of any potentially tradable item outweigh the foregone gains of market dependence. Because specialization and trade are inseparable, the transaction costs paid by a household both determine and reflect the diversification of its production portfolio.

The basic message thus is that of Hicks (1932) and later, for agriculture, that of Hayami and Ruttan (1985). Agricultural production decisions generally reflect technical choices that facilitate or catalyze the substitution of relatively abundant (hence cheap) factors of production for relatively scarce (hence expensive) ones. Technological adjustments that ease these factor substitutions release constraints imposed by resource scarcity. Production decisions and technical choices in agriculture are behavioral responses to particular constraints that both determine and reflect resource intensities and specializations. Shifts in production patterns are driven by changes in farmers' evaluations of the relative returns to resources employed in different pursuits, and on farmers' assessments of the range of feasible resource substitutions.

Implicit in analyses of small-scale agriculture that make transaction costs explicit is the recognition that farmers are not the only people engaging in economic activity in rural areas. Numerous traders are also important.[2] Most of these traders are small in size. Only a small minority deals in productivity-enhancing specialized inputs, despite the seemingly large unmet demand for these items in the areas in which they operate, i.e. from the farmers pursuing low-productivity production strategies (Freeman, 2001; Omamo, 1996). Fuller explanations for the persistence of small-scale DSO agriculture in Africa (within the constrained-maximization framework) thus extend beyond DSO *production* and account also for the small size of markets for productivity-enhancing agricultural inputs.

Consider this tale,[3] traders prefer to do business with people with good reputations, whom they can trust to follow through on agreements and meet

[2] Indeed, Fafchamps (in press) argues that market exchange plays a larger role in rural Africa than it does in developed economies, where exchange within hierarchical structures (e.g. corporations) is much more important.

[3] Our use here of the term "tale" and later of the terms "story" and "fable" is not intended to imply skepticism but rather to convey the idea that the theories being discussed rest on particular "story lines" or "story-sets".

deadlines. So do farmers. Because establishing trust and good reputations takes time and effort (and may be even tangible resources), it involves large sunk costs. But once trust has been established, it becomes the basis for a range of interrelated activities typically carried out within networks. There is no "market" for these contacts and thus returns to their possession will not be arbitraged away. New or potential entrants into a market, even those with superior technologies, will be at a disadvantage relative to those already in the market. But because existing suppliers have large sunk costs to cover, they charge monopsony or oligopsony prices. More than likely, therefore, rural markets for agricultural goods and services will have few suppliers. These effects will be reinforced by conditions in factor markets. For farmers will likely need credit. Traders will likely be the ones from whom they borrow. And so for identical trust- and reputation-based reasons, there will be only a few traders who supply credit, and they will do so only at high rates of interest. A self-affirming equilibrium will arise featuring a small number of traders–lenders advancing little credit, selling small quantities of inputs to a small number of trusted customers (farmers), who, because the credit and inputs are dear, will also have low effective demand for both. This will imply low incentives for traders to expand sales and capture scale economies that allow them to reduce costs. They will refrain from doing so. There will be no inherent pressures on either the farmers or the traders to take steps that would move the markets toward more competitive, lower cost structures. Prices of both inputs and credit will remain high, implying strong incentives for farmers to economize on input-use and instead pursue subsistence-oriented production practices.[4]

Such fables are intuitively appealing and edging steadily into the mainstream (e.g. Fafchamps and Minten, 2001a,b). Incorporating the network notion is especially powerful and fruitful (even though it is used to model individual behavior rather than the network structures and properties for which it has been developed (Wasserman and Faust, 1994)). But in assigning so pivotal (and decisive) a role to the notion of trust (yet still leaving it to be determined "outside" empirical models), these tales are something of a dead-end from a policy perspective. Trust is critical precisely (and perhaps *only*) because competition is imperfect (Burt, 1992). If trust is built and maintained in networks based on factors that are, by definition, not plain to outside observers, what can governments do about that? Should they try to discern the most contact-laden, network-based groupings and support their activities? Should, say, fertilizer policy in Kenya, or Uganda, or Malawi be Shah- and Patel-based? More important in the context of the current paper, these tales (and the equilibrium-based reasoning that underpins them) are clearly very able to point out small-scale agriculture's problems and how it can come to be "locked" in low-level, dynamic poverty "traps" featuring mutually reinforcing low demand and low supply for improved technologies. But they are silent on solutions, i.e. on "escape" routes. For each component of the equilibrium affirms the others, none more or less critically than the rest. And left vague are the processes through which the low-level technologies that purportedly underpin the traps actually come to be chosen, time and again.

And so lengthy and diffuse lists of policy prescriptions emerge, such as this from Friis-Hansen (2000): establish institutions capable of setting relevant quality standards, adjusting them to ongoing market changes, and enforcing them upon growers; offer small-scale producers and traders means to increase their market power; increase capacity of institutions at the primary-producer level to achieve the quality premia and integration required within increasingly externally controlled and managed supply chains; develop simplified procedures for protecting against dumping and countervailing duties; increase investment in rural transport, water, and processing infrastructure; abandon the current focus in research and extension on high use of external inputs and embrace instead low-external-input sustainable agriculture (LEISA); enact regulations that allow for diversification of sources and forms of input supply supporting agricultural production based on LEISA; institutionalize a perspective that views agricultural development policy as a component of rural development policy; abandon top-down approaches to rural development in favor of more decentralized and participatory approaches. Similar, albeit less detailed, listings of policy measures to improve prospects for sustained productivity growth can be found in Jayne

[4] This is an adaptation of sections in Burt (1992), Fafchamps (in press), and Hoff and Stiglitz (1998).

et al. (1999), Kelly et al. (1995), Kherallah et al. (2002), Reardon et al. (1997), and many others (see Omamo, 2003).

But surely all of this is the rub. *How* are Africa's cash-strapped governments supposed to do all these things? *How* are supposedly weak and poorly-performing public sectors supposed to design and implement even more complex and more management-intensive policy measures than are those they are clearly currently failing to design and implement? And even if the measures were to be successfully designed and implemented, *how* precisely would they achieve the broad-based productivity gains implicit in their impacts, i.e. via which mechanisms?

3. Learned routines

Small-scale farmers may indeed engage in constrained utility maximization. But like the rest of us, at best this is somewhere in "deep background". Meanwhile, what do they actually, consciously, *do*? Small-scale traders likely are motivated by the quest for higher profits (lower costs), but what, from day to day, do they actually *do*?

Invoking uncertainty (and risk) may not be necessary to capture several key features of DSO agriculture under the assumption of constrained maximization. But uncertainty is a central fact of all economic activity, including that in small-scale agriculture, not least because almost all small-scale production is rainfed. Following Rosenberg (1976) and Heiner (1988, 1989), we will propose that like all economic agents operating in uncertain environments, what small-scale farmers and traders spend the bulk of their time *doing* is looking for ways to address the problems posed by that uncertainty. To the extent that they identify any solution at all to a given problem, it is likely *not* an optimal one among many, nor was it intended to be. And so, in the spirit of Rosenberg (1976), we will identify considerable scope for "out-of-equilibrium" improvement in smallholders' production and trading systems.

Following Dosi and Egidi (1991), we distinguish between two kinds of uncertainty: *substantive* uncertainty (related to some lack of relevant information about environmental events) and *procedural* uncertainty (concerning a gap in requisite problem-solving ability). Most analyses of agricultural decision-making under uncertainty consider only the former kind of uncertainty (e.g. Anderson et al., 1977; Binswanger and Rosenzweig, 1986; Fafchamps, 1992). The implicit assumption is *substantive uncertainty* but *procedural certainty*. Specifically, smallholders are viewed to be unaware of all possible realizations of states of the world.[5] But they make the best possible use of the information available to them. Where possible, they transform uncertainty into risk and act according to the relevant probability distribution of a specific set of outcomes. Where such a transformation is not possible, "optimal inertia" may result as decision-makers self-insure, typically via seemingly inefficient extreme diversification of their production and investment portfolios (Bromley and Chavas, 1989; Fafchamps, 1992; Ferro, 1994). The possibility of gaps in smallholders' "information processing" abilities is not admitted, whether they are assumed to face familiar or unfamiliar situations.

But *new* technologies and practices are *unfamiliar* by definition. In considering whether and how intensively to use them, smallholders face conditions that require that they imagine situations that have never occurred in their pasts and thus require of them abilities and attributes that they likely have never had cause to build up. Successful adoption and utilization of a new technology thus is far from trivial. "Choice" of a new technology is but the terminal stage in a multi-step process that includes formulating the problem itself, identifying the relevant information, applying pre-existing abilities or developing new ones better suited to the problem solution, and finally, identifying alternative courses of action only one of which is selected (Dosi and Egidi, 1991).

Competence—i.e. the ability to complete this multi-step process toward a course of action—thus is key and cannot be assumed present. For it has not only a technical dimension, but also an organizational one. Technical competence refers to certain interrelated abilities (skills): the ability to develop and design new products and processes; the ability to operate facilities effectively; and the ability to learn. Organizational competence also has interacting components: allocative competence (deciding what to produce and how to produce it); transactional competence (deciding

[5] Hereafter, we use the term "smallholder" to refer to both small-scale farmers and traders.

whether to make or buy, and whether to do so alone or in partnership); and administrative competence (knowing how to design organizational structures and policies to enable efficient performance). Technical competences tend to be more product-specific than are organizational ones (Dosi and Marengo, 1994).

Africa's smallholders are clearly highly competent practitioners of DSO agriculture, whose prominence as an economic activity suggests that contemplating alternative (competing) technical and organizational arrangements will imply *both* substantive and procedural uncertainty for smallholders. They may indeed respond "rationally" to these two kinds of uncertainty. But this "rational" behavior does not necessarily mean "most robust" or "most efficient" in an optimizing sense. Rather, procedural uncertainty and competence limitations mean that these responses will represent "institutionalized" behavior—institutionalized in the sense that smallholders will bounded rationally settle on relatively stable "rules" or "routines" (or problem-solving heuristics[6]) that are context-specific but to some extent event-independent (Dosi and Nelson, 1994; Heiner, 1993; March and Simon, 1993; Nelson, 1994; Rosenberg, 1976). Routines thus are specific to particular *classes* of problems and to the people and the organizations who have developed them. The transferability of these routines across people or organizations is defined by their degrees of tacitness and the nature of the knowledge involved in their original generation and implementation (Winter, 1982).

Routinized behavior is not only efficient; under both substantive and procedural uncertainty it is likely more so than behavior emerging from optimizing procedures (Heiner, 1988, 1989; Rosenberg, 1976). For productivity growth (technical advance) hinges not only on the improvement of individual technologies, but also on expanded use of more productive *existing* technologies relative to less productive *existing* ones. The latter phenomenon is a more potent source of productivity growth when, as in most agricultural settings, there is large variation in productivity across extant technologies (Dosi and Nelson, 1994).

Abilities (skills) are formed in individuals, routines are developed in organizations (Nelson, 1994; Winter, 1982). Both individual skills and organizational routines emerge through *learning-by-doing* in that they are developed in particular contexts and circumstances to meet pragmatic standards (needs) of technical and economic adequacy (Rosenberg, 1976). The effectiveness of a skill or routine thus is shaped by the learning process, which is dependent on the environment in which it is developed. A *current* competence therefore implies *past* learning. And *distributions* of competences rest on *patterns* of learning. Together, these contribute to differentiation across economic agents and help shape their strategies.

Competences, organizational forms, and learning patterns are therefore jointly determined; all display inertia and path-dependence through time. One cannot easily adjust learning to any organizational form or competence; one cannot quickly reshape organizations in light of changing learning environments; one cannot promptly acquire new competences irrespective of extant organizational forms and past learning experiences. Observed patterns of production and trade—such as those that characterize DSO agriculture—thus are neither accidental (i.e. lacking a deeper rationale) nor ephemeral (i.e. apt to disappear if, say, realized transaction costs imply different utility- or profit-maximizing configurations of production and trade).

In this schema, an "agricultural technology" is more than an "input" or "combination of inputs"—e.g. a given pesticide or a particular seed–fertilizer package—but rather a routine that codifies a set of procedures, and the knowledge involved in the solution of particular classes of production problems. An African smallholder's farming or trading enterprise is just as much a formal organization as is a global corporation (Gans and Quiggin, in press). DSO agricultures thus are not mere *technical responses* to extant conditions, but also *organizational manifestations* of extant competences and the learning patterns these competences determine and reflect.

Closely related to the notion of competence are two others: *coherence* and *flexibility*. Coherence refers to the relatedness of lines of activity within an economic unit in terms of commonality of technological and market characteristics (Teece et al., 1994). Organizations add activities that relate to some aspect of their existing ones. They build on what they have; they build on what they are doing; they build on what they

[6] An heuristic is any principle or device that contributes to the reduction in the average search to solution (Winter, 1982).

already know. New product lines thus bear certain technological and market similarities (complementarities) with the old. The less related is a potential new activity (routine) to existing ones, the less likely that it will be added to the set of existing activities (routines), and vice versa.[7] The flexibility of a particular technology (or a particular body of knowledge) pertains to the opportunities it offers for generating a wide set of efficient routines. It thus relates to that technology's generality and robustness (its "abstraction"), i.e. to the width and range of the set of problems to which it can be successfully applied (Dosi and Egidi, 1991).[8]

Like competence, therefore, both coherence and flexibility impart inertia and path-dependence to economic activity. New products and processes may affirm extant competences, coherences, and flexibilities, or they may not.[9] And because competence, coherence, and flexibility are inherently *relational* phenomena, these effects may cover large collectives. The set of technological *opportunities* that lie before a given farmer, trader, region, or sector thus will also be path-dependent and inertial. These opportunities will also be incompletely discerned and understood, requiring investments in learning (by-doing).

Based on collective outcomes of learning experiences with these opportunities, given lines of economic activity and the farmers, traders, and regions concentrating on them will be selected (weeded out). Survival will depend on the *selection environment* and the mechanisms that systematically "winnow" on the variations and perturbations in that environment (Nelson, 1994). In African agriculture, this environment is defined in large part by the inherently imperfect nature of competition in agricultural markets (Fafchamps, in press) and by political forces that give competition its *actual* expression (Bates, 1981, 1989).

Technical change (and innovation) in small-scale agriculture thus is similar to that in other branches of economic activity in that it involves generation of new (adaptive) routines and rules (i.e. new heuristics) under limited structural knowledge (Heiner, 1992). These new routines may relate to a new production process—i.e. different, more efficient rules for transforming certain inputs and information into given outputs—or to the conception of a totally new product, or entirely new organizational set-up. The empirical counterpart of these problem-solving procedures thus comprises organizational tasks ranging, say, from how to most efficiently save seed from one growing season to the next on-farm, to how to procure farm inputs from distant sources. What a smallholder "knows" thus is mainly stored in her behavioral rules and is reproduced-, augmented-, changed-by-doing, i.e. via the actual implementation of problem-solving routines. Competence thus means both *doing* well and *learning* well.

Viewing smallholders first and foremost as learners and problem-solvers is certainly not inimical to perceiving of them as economizers on production and transaction costs (Heiner, 1989). The key difference lies in whether smallholders are assumed to have their problem-solving procedures and their hierarchical structures correct or not (Dosi and Egidi, 1991). Here, they are assumed *not* to have these procedures and structures fully in hand, at all times. They are thus assumed to be engaged not in pared-down transaction cost-reducing "games" with one another, but rather in more complicated (but richer) ones against the changing biophysical and socioeconomic environments with which they are confronted.

The following proposition summarizes our argument.

Proposition 1. *DSO agriculture in Africa is more than a collection of individual technical "choices" in response to extant biophysical and socioeconomic conditions. It is also a cumulative collective outcome of routines (rules) that spring from the technical and organizational competences of farmers, traders, and other rural dwellers, and from learning patterns that these competences determine and reflect. The*

[7] Coherence thus is distinct from specialization, which refers to performance of particular tasks. The activities of a given farmer or trader may exhibit coherence though they may not necessarily be specialized in the sense of high concentration of resources and effort along a particular line. Conversely, a highly diversified farming or trading unit may be coherent in the sense that various lines of activity have several common technical and organizational features (Teece et al., 1994).

[8] More formally, the flexibility of a technological routine relates to its robustness in dealing with substantive uncertainty, where this uncertainty stems from the high dimensionality of the event-space and the incompleteness of decision-makers' ex ante knowledge (Dosi and Egidi, 1991).

[9] For instance, they may enhance or destroy the value of "complementary assets" built up in prior activities.

resilience and ubiquity of DSO agriculture rest on the flexibility and coherence (*and complementary asset requirements*) *of its technical and organizational routines, which together impart path-dependence to learning patterns, technological opportunities, and technology selection. Since most of Africa's smallholders are not cushioned from market rationality, the principal selection mechanisms in African agriculture are inherently imperfectly competitive markets. Only the most efficient smallholders survive, where that efficiency relates to coherent and flexible routines developed to accommodate the substantive and procedural uncertainty intrinsic to agricultural production and trade under imperfect competition and extreme biophysical and socioeconomic diversity.*

4. Dynamic macro effects

Patterns of trade track income levels and long run trends in income distribution. International comparative advantage implies that macroeconomic growth prospects hinge on income-intensities and income elasticities of commodities produced and traded on national and world markets. Different commodities and sectors can exhibit highly distinct dynamic potentials in terms of economics of scale, technical progress, possibilities for division of labor and learning-by-doing (Arthur, 1988). Specializations that are efficient in terms of comparisons of extant sets of input–output relationships may not be so upon assessment within the plane of a longer time horizon. Because, as outlined above, technological learning processes are generally associated with actual processes of production, new and promising technologies tend to be characterized by high rates of innovation; they also exhibit idiosyncratic processes of learning and appropriation that militate against easy diffusion (Arthur, 1988; Winter, 1982). Rapid learning breeds the ability to subsequently migrate incrementally to products and activities at greater technical sophistication and institutional (e.g. market) distance, and vice versa (Dosi, 1988). These processes select areas where technical skills are accumulated, innovation undertaken, economies of scale reaped. Technology "gaps" emerge (and expand) as promising technologies progressively attract greater learning, and as impediments to diffusion are progressively overcome (Dosi, 1988).[10] For, again, within each technology and each sector, technological capabilities and learning processes derive from actual processes of production. Under such conditions of dynamic increasing returns to technology adoption and learning, there is no straightforward way in which markets can relate varying future growth efficiencies to current relative profitability signals. "The ordinary messages of the market are general and not sufficiently specific", notes Rosenberg (1976). "The market rewards reductions in cost, but this is true of *all* reductions in cost, wherever attained. It does not specify the directions in which cost reductions should be sought" (p. 123).

There is every reason to expect these arguments to hold for agriculture in Africa, not least because agriculture—and agricultural trade in particular—so dominates value added on the continent. By implication, to the extent that small-scale African agriculture has become "trapped", then it is to the degree that small-scale competent practitioners of the microeconomically competitive (efficient) DSO agriculture are producing and trading commodities that a progressively decreasing number of people in domestic and world markets wants to buy. It is also "trapped" to the degree that smallholders are producing these items in ways that a progressively decreasing number of people and organizations wants to learn more about, and improve. There thus appears to be a major contradiction between the microeconomic allocative (static) *efficiency* of DSO agriculture and its dynamic (growth) macroeconomic *inefficiency*. That tension likely varies across countries in proportion to the distances separating their DSO agricultural technical and organizational arrangements with those (arrangements) at "frontiers" represented by the newest and most promising technologies.

5. Policy implications

If our proposed perspective has merit and the learned routines embedded within DSO agriculture

[10] Dosi (1988) also notes that, historically, successful "catching-up" efforts (in terms of per capita incomes and wages) have always been accompanied by technological catch-up in the new and dynamic technological paradigms, "irrespective of initial patterns of comparative advantage, specialization, and market-generated signals". We will return to this point later.

have indeed given it a "selectional advantage" over other, better ("fitter") patterns,[11] the policy challenge is even greater than that broached at the outset, i.e. how to spur self-sustaining productivity growth in African agriculture. Our proposition implies that nothing short of a *radical technological discontinuity* will change the path of African agriculture toward one of sustained and equitable growth. *How* can such a discontinuity be brought about? *How can it be made to happen*?

Viewed this way, the central policy question is how to achieve increasingly higher *organizational payoffs* in agricultural technology development and diffusion via progressively more broad-based learning about new and promising technologies. This implies that the issue is not as much "market failure" (e.g. Kherallah et al., 2002) as it is "system failure", where the "system" straddles markets, political and administrative units, and agroecosystems.

The challenge is not as much how farmers can better participate in agricultural sectors (e.g. Chambers, 1983, 1997)—and in agricultural technology development and diffusion in particular—as it is how to transform the highly clustered, one-dimensional, and static systems (in which most of them already participate) into more open (random yet still clustered), multi-dimensional, and dynamic ones (in which their participation will be more rewarding *to them*).

And the problem is not as much how to conserve natural resources in small-scale agriculture (e.g. Barrett et al., 2000) as it is how smallholders can be assisted to develop technical and organizational routines that permit them to accommodate the combination of biophysical and socioeconomic effects that make resource degradation central in extant routines.

Our perspective therefore resonates strongly with Schultz's (1964) "poor-but-efficient" portrayal of peasant farmers. Schultz's central hypothesis was that there is little significant allocative inefficiency in the "economic routine" of "traditional" agriculture, where factors of production are those at the disposal of particular communities, and that smallholders' continued application of individually efficient methods was inefficient on aggregate. Our arguments also identify farmers' (and traders') routines as keys to both the resilience of DSO agriculture and to any movement out of its grip. More than 40 years after Schultz proposed the poor-but-efficient hypothesis and linked it to the routines embedded in smallholder agriculture, those routines remain largely unexamined. We would therefore join Barrett (1997) and Omamo (1998a) in questioning the validity of findings of inefficient behavior by smallholders.

Our perspective also sheds new light on the institutional underpinnings of agricultural science and technology policy in Africa and elsewhere in the developing world. A basic recognition is that agricultural innovation and diffusion have an intrinsic *dual nature* in that they are highly *clustered* at local levels but also highly *dispersed*, both spatially and institutionally. Technology development is highly dependent on both local context and linkages with wider processes of change and coordination in agricultural sectors. We would argue, therefore, that a fundamental but largely unstated puzzle in the large literature on farmer participatory research (e.g. Biggs and Smith, 1998; Chambers, 1983, 1997; Gass et al., 1997) is how local clustering processes can be strengthened while global dispersion is bridged.

We would further suggest that efforts toward greater clarity and consistency in agricultural research planning and program formulation (e.g. Alston et al., 1995; Norton and Pardey, 1987; Norton et al., 1992) are at base efforts to identify institutional arrangements and organizational forms that can support rapid dissemination of information without necessarily compromising behavior that is individually costly but beneficial when reciprocated, e.g. farmer uptake of improved technology *and* trader commitment to provide related inputs or purchase resulting outputs. It is likely that some farmers and traders who *do* adopt and *do* commit will be interacting predominantly with traders and farmers who do *not* commit and do *not* adopt. Such farmers and traders will fail to reap the benefits of reciprocity. "Cooperators" located within the same locales (clusters) may survive, even thrive, in the midst of "non-cooperators". Conversely, any small group of initial cooperators may be eroded from the periphery by non-cooperators.

Our perspective therefore throws up two kinds of policy instruments: "passive" measures and "active" measures. We define "passive" measures as those that rely "blindly" on decentralized activity within existing

[11] Where, again, the term "fitter" refers to technologies with superior long run (macroeconomic) potential.

institutional and organizational structures; we define "active" measures as those that involve manipulation of those structures toward given ends.

First, the "passive" agenda. Our proposition of a low-demand, low-supply trap built on DSO agriculture suggests a structural need for policies affecting patterns of economic signals (including relative prices and relative profitabilities) as they emerge from the international market. That need, Dosi (1988) argues, will be sharper the greater the distance of any one country from the technological frontier represented by the newest and most promising technologies on offer.

This appears at first to be a reactionary (throwback) argument in favor of vilified incentive-distorting "protectionist" measures: price subsidies, preferential tax exemptions, import duties and tariffs. While experience thus far with agricultural market liberalization in Africa has largely defined the *limits* on agricultural markets on the continent (i.e. major capital and infrastructural constraints, significant transaction costs, and as a result, several non-competitive elements in such markets), prior experience with agricultural market *control* on the continent was a practical lesson in the *negative* power of these "passive" instruments.

But our argument is not based on the simplistic "infant-industry" ideas or vague appeals to "public goods" that were used to justify control regimes. Offered today, such notions would still be open to opportunistic interpretation by beleaguered governments. But more importantly, their negative dynamic impacts would undermine any positive current impacts. For instance, in Zambia, recent wide scale fertilizer and seed subsidies (ostensibly to jumpstart productivity and generate demand for greater quantities of the inputs) have "crowded-out" the private sector in fertilizer and seed procurement and distribution.[12]

[12] The subsidy program has rendered major investments in input marketing made by large private concerns considerably less profitable than was projected. These investments were undertaken with encouragement of the Zambian government. The subsidy program now appears to be financially unsustainable. Large-scale private sector investments in input procurement and distribution will likely soon be needed. But having singed the private sector by its subsidy policy, and knowing full well that market-based prices for fertilizer and seeds will lie well above those currently being paid by farmers, the Zambian government faces a major challenge in convincing the private sector to cooperate, and the farming community to once again accept higher prices for these key inputs.

Our argument is subtler.[13] It relies on the emergence of *externalities* resulting from interactions among decisions of *behaviorally unrelated* decision-makers. Specifically, where specialized (improved) intermediate inputs—such as inorganic fertilizers and hybrid seeds—are in limited supply (e.g. due to poor market development or credit rationing to the agricultural sector), they are dear. The potential users of these inputs (final-goods producers, in our case smallholders) are forced to employ less productive labor-intensive practices, further lowering inducements to suppliers of the specialized inputs. The key recognition is that *pecuniary externalities* (spillovers) that would otherwise emanate from factor substitutions in the *final-goods sector* do not materialize. Further, limited demand implies that the large sunk costs commonly found in *intermediate-goods sectors* that might serve as *incentives* toward expanded supply (to capture scale economies) work instead in the opposite direction and serve as *barriers* to entry and expansion. Absent (externally) altered price incentives in either the intermediate-goods sector or the final-goods sector, no mechanism exists that will move the system away from the *low-supply, low-demand trap*.

However, policy measures that aim to change one incentive never cut in that direction only (Schultz, 1978; Timmer et al., 1983). The basic rationale of "passive" but interventionist policies that target incentives thus cannot be that they are a means to influence smallholder *behavior* directly, i.e. on their own account. In time, a counteracting impact invariably emerges on the other side of the market. In our schema, the justification for "passive" incentive-targeting measures can only be that they can support the appearance (and institutionalization) of particular organizational forms and learning regimes in agriculture, i.e. by making available forms of market stabilization that only a government can provide, but only in return for commitments from key sector stakeholders that they will *invest* in certain organizational forms and learning patterns.[14]

[13] Certain elements of this argument, albeit in a different context, can be found in Arrow et al. (1998), Ciccone and Matsuyama (1996), Krugman (1991), Murphy et al. (1989), and Rodriguez-Clare (1996).

[14] Sabel (1994) describes such strategies in Japan's industrial sector.

This defines the "active" policy agenda, i.e. specifying the desired organizational forms and learning patterns, catalyzing and facilitating their appearance, and monitoring stakeholders' adherence to commitments.

Again, the basic organizational challenge is defined by the nature of agriculture in Africa: how to retain the high degree of local clustering essential to discovery and adoption of agricultural innovations under extreme biophysical and socioeconomic diversity, while promoting diffusion of innovations by bridging the global dispersion (separation) that defines small-scale agriculture. This challenge points to a role for "bridging institutions" (or as Watts (1999, p. 77) might put it, "shortcuts") of various kinds. For instance: those that catalyze improved integration of activity along the continuum from basic, to applied, to adaptive research; those that help convert technically workable innovations into commercially feasible ones; those that support broad-based experimentation with new procedures by helping to transform generalized (substantive) uncertainty into manageable risk; those that act as "focusing devices" for this experimentation, i.e. by linking current directions and contents in trial-and-error activities to desired future outcomes; those that increase amounts of global information at local levels and thus help override the overwhelming influence of transport costs in farmer–trader and trader–trader interactions (i.e. in the expected continued absence of major investments in rural infrastructure).

These bridging institutions will be context-specific. However, a range of options is already being explored across the continent. For example, support for, and active participation in, formation and functioning of farmers' associations (Dorsey and Muchanga, 2000); support for, and active participation in, formation and functioning of industry associations, comprising not only producers (farmers) but also traders, manufacturers (processors), and scientists (Agriforum, 2000); support for organizations that link farm input supply with information dissemination (Seward and Okello, 2000); support for organizations that explicitly integrate research and outreach activities (NARO, 2000); support for organizations that explicitly integrate research and outreach with training (AERC, 2000); support for improved agricultural market information systems (KACE, 2002); support for development, testing, and dissemination of improved post-harvest commodity management methods (Foodnet, 2002); support for theme-based competitive research grant programs (ASARECA, 2002).

6. Conclusions

Small-scale agricultural production and trade in Africa would seem to contain many individual and organizational capabilities with efficiencies that are clearly very real but not at all well understood. It is hence a world of uncertain scope that is subject to disruption if the biophysical and socioeconomic environment starts to behave in novel ways. Such disruptions may affirm the viability of extant low-productivity production and trading systems, and the organizational forms and learning patterns these systems determine and reflect. Or they may occasion a round of troubleshooting, learning, and adaptation toward greater productivity. Our aim in this paper has been to offer persuasion in favor of the latter possibility, and to propose a perspective for agricultural science and technology policy design and implementation that promotes that possibility. We are painfully aware of the exploratory, and often highly tentative, nature of our analysis. But the state of our ignorance of small-scale agricultural production and trading systems in Africa persuades us that an authoritative treatment is not on the horizon.

Rosenberg (1976) suggests that, "If we would like to understand the kinds of problems to which technically competent personnel are likely to devote their attention, we must come to grips with their inevitable preoccupation with day-to-day problems posed by the existing technology. ... If we pay more attention to the cues thrown out by this daily routine, we may gain a clearer understanding of the process of technical change" (p. 125). We have embraced such a viewpoint in the paper. Our analysis suggests that developing relevant and consistent agricultural science and technology policy frameworks in Africa requires increased understanding of several as yet largely ignored issues: the nature of learning processes among farmers, traders, and other agricultural sector participants (including policy makers); the organizational forms that these learning patterns condition and are exposed by; the mechanisms of discovery and adaptation underlying agricultural innovation and diffusion;

the selection environment for these innovations; the comparative efficacy of alternative institutional arrangements (i.e. governance structures and processes) in agricultural R&D and how that efficacy varies, on one hand, with the (macro) policy and institutional environment within which agricultural R&D takes place, and on the other, with the attributes and behavior of economic actors.

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