Path dependence and implementation strategies for integrated pest management

Hendrik Wolff and **Guido Recke***

Institute of Agricultural Economics, University of Göttingen, Germany

Summary

The enhancement of Integrated Pest Management (IPM) in order to secure a sustainable development has been often propagated. In many states of the world, politicians as well as development agencies have worked out strategies dealing with the question of how IPM could be implemented in agricultural practice. Within the field of evolutionary economics this article examines the concept of path dependence. On the basis of this theoretical framework implementation strategies are designed for IPM in Ghana. Even though the concept of path dependency has been frequently used to explain adoption phenomenon in the sector of high technology, this has not been the case in the field of agricultural development. In the light of this the analysis should also reveal the significance of path dependence as an instrument for ex-ante policies.

Keywords: Path dependence, integrated pest management, crop protection, network externalities, uncertainty reduction, scouting service, Ghana

Introduction

Recent literature on path dependence in the economy has helped to enlighten the mechanisms by which systems develop. In this article, the concept of path dependence as applied to development policy will be examined. It focuses on aspects which may lead to a better understanding of the development of guidelines for the IPM. In particular, two crop protection strategies – the Chemical Crop Protection (CCP) technology and the technology of IPM - will be examined within the theoretical framework of path dependence.

Pesticides have been known to induce changes in agricultural and ecosystems. Despite their positive effects, pest resistance, the destruction of beneficial

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organisms and the potential hazard to the environment as well as human health have caused increased concern. RACHEL CARSON'S (1962) "Silent Spring" offered 'biological solutions' to pest control, embodied in the chapter entitled "The Other Road". Since then, the research into alternative control methods has increased significantly and today IPM is regarded as an imperative in the development of world-wide guidelines for sustainable agricultural production. In developing countries, efforts are being undertaken to adopt this new technology. However, the success of such IPM programmes is poor and, at the same time, pesticide misuse is still alarming (VAN EMDEN and PEAKALL, 1996).

The path dependence theory provides a theoretical concept for analysing the competition between two technologies.[1] It examines the reasons why one ex post inefficient standard is applied by its users in spite of the existence of a superior technology. The existence of dynamic increasing returns implies that a path, once chosen, will become entrenched, which explains why we still have not gone off to "The Other Road", about which RACHEL CARSON wrote. It will be further argued that the path dependence theory provides a good instrument for designing policies for the implementation of technologies of which the adoption is socially desirable. Examples and figures are derived from the case study of plant protection of two tomato production systems in Ghana (WOLFF, 1999).

1. The path dependence theory and pest control

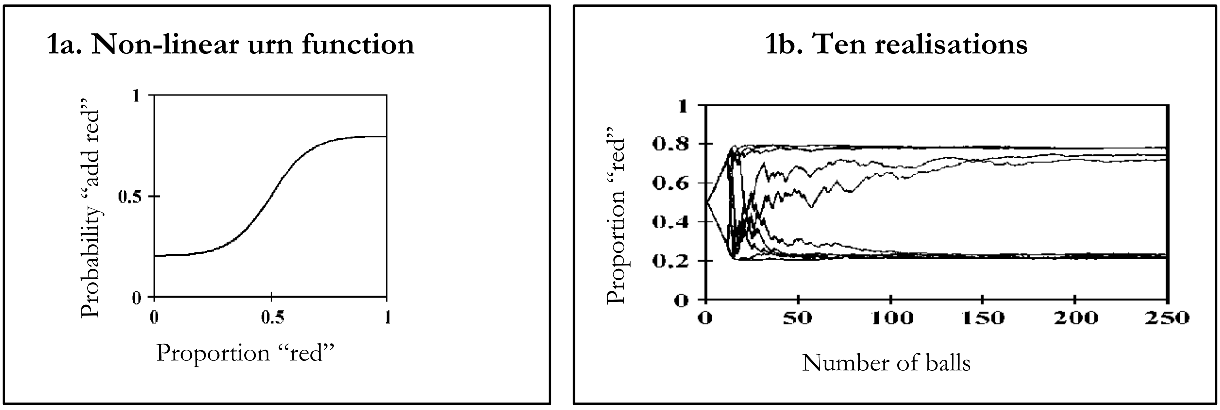
1.1 Principles of path dependence

Since the mid-eighties, the concept of path dependence has been used to explain various economic-technical phenomena. The theory incorporates a newer

[1] The path dependence theory is not the only concept which explains the difficulties and the delay in implementing IPM. Other well examined models have already provided answers: the existence of institutional arrangements and policies often pre-condition the continuing dependence on pesticides which can impede the diffusion of the IPM-technology. This leads to a divergence between social and private costs, so that individual farmers do not pay the costs of the negative effects of chemical use. Furthermore, it can be argued that most of the means for CCP are provided as private goods by the chemical industry releasing their products with a high amount of promotion. This can lead to a further adoption of CCP. However, IPM is often seen as a good with a much stronger grade of publicity and therefore does not gain in such an extend from sponsoring. It therefore needs support by the society. Various studies have been carried out on these subjects, e.g. AGNE (1996), CARLSON and WETZSTEIN (1993), FERNANDEZ-CORNEJO (1996), FLEISCHER et al. (1998), JUNGBLUTH (1996), WAIBEL (1994), WAIBEL et al. (1999).

economic feature, namely the evolutionary aspect of the economic process. Such systems, as they depend on their historical development, may be balanced on different equilibria. The concept of multiple equilibria constitutes a main difference from the traditional theory of the neo-classicists, who take just one equilibrium into consideration, which is obligatorily met through market-mechanisms. Further, the neo-classical theory cannot explain the reasons why a Pareto superior technology is not adopted. In comparison, the concept of path dependence does better in explaining the adoption processes. It should be considered as one of the most fruitful concepts within the field of evolutionary economics (BRANDES et al., 1997). Some famous examples of path dependence are in the field of industrial standards such as the dominance of the QWERTY typewriter keyboard (DAVID, 1985), the gauge of railway tracks (PUFFERT, 1991), or the competition between the video recording systems. In the beginning more than one path could be selected and the system could be balanced on different equilibria. However, after a certain path has been chosen, it is hardly possible to abandon it. That is why the phenomenon is called path dependent.

Figure 1. A non-linear stochastic polya process



Source: BRANDES et al., 1997

A mathematical description of the path dependence theory is a very complex task. Therefore, in the present study merely the concept will be described. However, an example of a path dependent process is quite easy to illustrate by means of a non-linear stochastic POLYA process: In the period t = 0 an urn contains two balls, one is red and the other blue. One ball is randomly drawn from the urn. This ball and one additional ball of the same colour must then be added into the urn. The probability of encountering a red ball is represented through the non-linear probability function

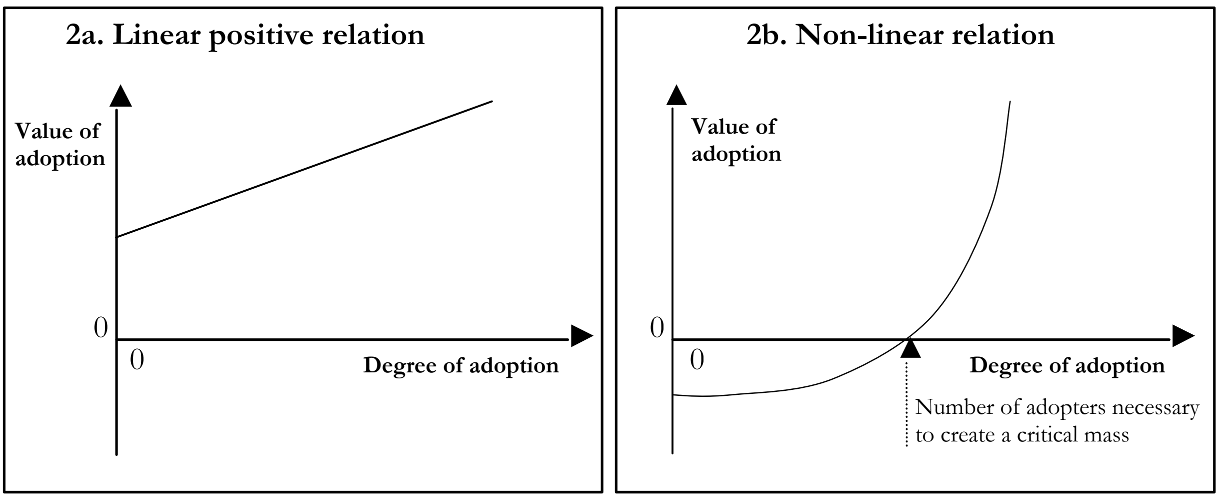
$$\text{Probability(“add red in t+1”)} = \text{f(proportion of red in t)},$$

depicted in figure 1a.[2] Ten simulations are plotted in figure 1b. In the early periods, the proportions are subject to large fluctuations. If the repetition of draws increases, the effect of an added ball on the proportion decreases. The paths stabilise towards the equally likely equilibria (attractors) around the limiting values 0.2 and 0.8 (BRANDES et al., 1997).

The Polya process suitably illustrates the way in which equally likely equilibria can develop over time. However, it cannot be claimed that the introduction of a new technology follows simple (non)-linear processes (ARTHUR et al., 1987; BRANDES et al., 1997). Also it is formally very difficult to explain path dependency by means of a stochastic concept and thus, in theoretical literature non-linear deterministic systems are preferred (BALMANN, 1994).

Theoretical work on competing technologies has focused on the possibility of a market failure. If there are two technologies, the superior one may disappear from the market while the inferior one persists. The formula that states, 'the value of adoption of a particular technology rises with the degree of adoption of that technology', is central to this research (COWAN and GUNBY, 1996: 523).

Figure 2. Examples of the relations between the value of adoption for an individual user of a technology and the degree of adoption of the technology



[2] whereby $f(x) = 0.2 + [0.6/[1 + \exp(-12(x - 0.5))]]$

The following different aspects regarding the degree of adoption and its relation to the value of adoption can be found in scientific publications: Learning, uncertainty, network externalities, sunk costs in kind of fixed assets and sunk costs of human capital. All these forces can operate as positive feedbacks, making technologies more valuable as the number of users increases. In abstract terms, it can be described as illustrated in figure 2, with the value of adoption for an individual user expressed in monetary terms, and the degree of adoption expressed either in the number of individual adopters of the technology, in time or in an aggregated market value. In the case of figure 2a, a positive linear correlation exists. Since for the first individual user the value of adoption is positive, the technology could be easily adopted. Within the degree and value of adoption co-ordination system, other non-linear relations can be illustrated too: In figure 2b the adoption process is subject to much stronger increasing returns to adoption. However, the first users would suffer a period of low payoffs and thus the adoption process stalls. The tragedy of this is that the switch does not occur, even when the new technology is clearly superior to the old, and the sum of the private costs of switching to the new one is less than the sum of the private benefits. Thus, the individual value of the technology may vary greatly from the social value. The phenomenon depends also on the number of users who switch at the same time (critical mass). For example, the use of certain natural enemies may be only feasible if many farmers in the area co-operate. This will increase the preservation and distribution of the bio-control agents (REICHELDERFER, 1981). The value of their use will thus increase. By contrast, one farmer using the natural enemy only will find the population rapidly diminished by insecticides sprayed by neighbouring farmers. The possibility, however, to switch at any given time is not realistic. Mostly, under usual circumstances[3], there is no naturally given co-ordination among the users to switch simultaneously.

According to ARTHUR (1988a, 1988b), systems that operate under these 'increasing returns to adoption' tend to share, among other features, the following:

[3] A non-usual-circumstance would be if a heavy exogenous impact affects an installed base which is then destroyed. All former participants of the system will have to seek a new system. Such an impact was, for example, the 1983-bush fire in Ghana where the cocoa plantations were completely destroyed. The source of path dependence, sunk cost (cocoa trees), was eliminated. Had its reestablishment been considered, this would have lead to high fixed costs. As a result farmers sought new and quick income possibilities with few up-front costs and started vegetable production.

1. *Lock-in*: A system that generates strong positive feedbacks finds a stable equilibrium (lock-in). This can only be changed when other strong and significant influences come into effect which might push the system towards a new equilibrium.

2. *Inflexibility*: A path, once entered, can possibly only be abandoned at extremely high costs.

3. *Potential regret*: There is a possible inefficiency of the system. In a competition between technologies, it is not necessarily the best solution which triumphs, but rather that which has made a better start and managed to quickly build up a critical mass of users which will attract even more users.

4. *Multiple equilibria*: In contrast to the orthodox neo classical theory, more than one equilibrium may exist. Which of these attractors will be achieved depends on the historical development.

1.2 Comparison of the two pest control strategies

For the purpose of this analysis, two pest control strategies, the CCP and the IPM, are referred to. These two strategies are competing technologies to which sources and features of the path dependence theory are inherent.

Many definitions of IPM exist. However, the important aspect of this approach to remember is the incorporation of the affected ecosystem into the control strategy. The aim is not to control the short-term pests in a limited area, but to use natural factors sustainably, thus preventing the outbreak of pest population. The IPM approach includes the factors time, space and multi-factorial environment. IPM-programmes are thus specific to the crop, region and time for which they are designed. Against this background it is understandable that crop rotation is one of the most important methods of IPM (DAXL et al., 1994).

CCP consists of the application of pesticides in order to kill offending pests. CCP is typically applied by timetable spraying with dosages that are fixed. There is only a very limited response to current conditions in the use of this strategy – e.g. the decision to spray may depend on the current weather condition. However, the objective of the fixed control schedule is to avoid physiological damage.

Comparing both technologies, some basic features are important:

1. The two technologies show significantly different equilibria (or have different attractors, in the language of path dependence). The CCP attractor is the point at which a total elimination of all pests in the production process is achieved. With IPM, however, a long-term equilibrium between the environment and the agricultural production system will be achieved.

2. CCP involves variables of a static system only. IPM techniques, however, comprise the dimensions time and space and should only be analysed with a dynamic approach.

3. CCP techniques attempt to eliminate all pest organisms in the surroundings but also kill the beneficials. IPM, however, allows some physical damage if the value of loss is less than the cost of controlling the pest. 'It is thus based on the notion of economic rather than physical damage' (COWAN and GUNBY, 1996: 525). IPM takes advantage of the natural controls and works with the natural forces rather than against them.

For the following it will be assumed that CCP is the inferior technology with regard to the agricultural sector and for the society as a whole. Therefore, IPM as the superior technology should be implemented. Empirical studies to discuss the problem of testability and the duality of plant protection technologies can be found in the literature of COWAN and GUNBY (1996), FERNANDEZ-CORNEJO (1996) and VAN EMDEN and PEAKALL (1996) and their cited literature.

1.3 Reasons for path dependence

In this chapter, first four endogenous factors and then one exogenous factor for path dependence will be described. Their election results from their importance in the adoption process in plant protection technologies.

1.3.1 Individual learning

The very fact that agents can access information and knowledge through their own actions already entails the possibility of increasing returns (DOSI, 1997) enhancing path dependent processes. When a technology improves through learning by doing, the experience gained will increase the benefits of adopting it (ARTHUR, 1988a). In the case of competing technologies, this implies that a lead in market share can push a technology along its learning curve, and this makes it more valuable for adopters than its competitor (COWAN and GUNBY, 1996).

IPM is considered as a technology which demands a high level of information and knowledge. The pest management skills to be learned at the farm level are very complex. Thus, the individual farmer may first suffer an initial period of low payoffs before he benefits from his gained experience. This implies that the value of adoption would increase with time and as more farmers gained experience with the technology. This is, of course, also true for the gathered experience in the CCP-technology like the techniques of application, choice and dosage of chemicals for the various crops and the R&D undertaken in the laboratories of the pesticide industry.

1.3.2 Level of implementation

At the aggregated level in the learning about technologies process, the following three features can be attributed to information:

? The cost of acquiring information is mainly upfront, but thereafter, information can be utilised at any scale of output. Information-intensive technologies thus operate under fixed costs and falling average costs, since the information, once produced, becomes cheaper to reproduce (COWAN and GUNBY, 1996; DOSI, 1997).

? The information of a technology has non-rival use, meaning that if one person uses the information and knowledge of a technology, it does not prevent other users from adopting it too.

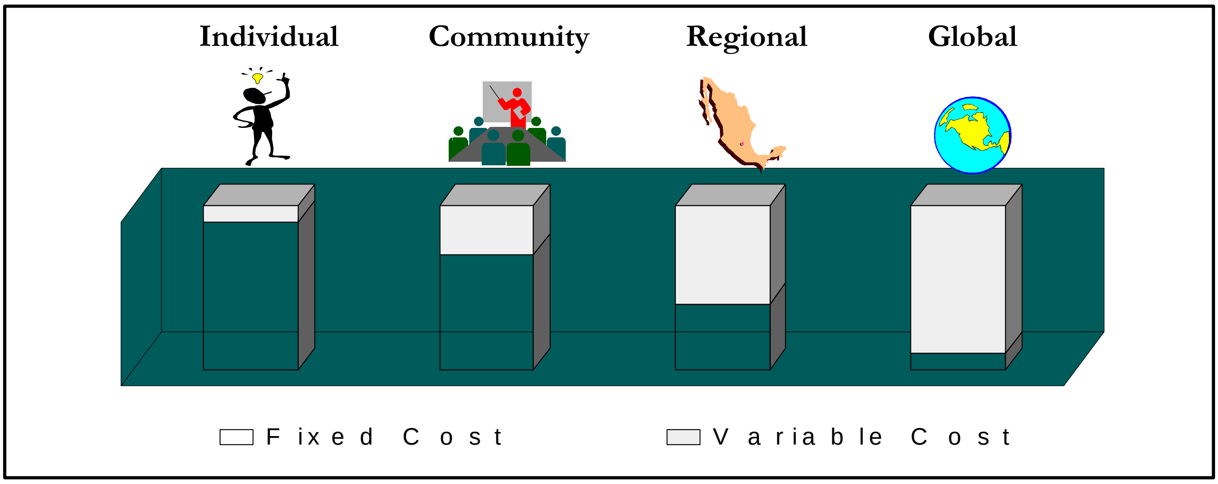
? Information and knowledge are inputs which are not used up through the production itself (DOSI, 1997). They can be passed on to other users.

COWAN and GUNBY (1996) distinguished between learning processes on global, regional and farm levels. The cost structure of learning about the technology can be divided into fixed[4] and variable costs. The more learning takes place at the global

[4] Fixed costs are defined differently from sunk costs. However, for the purpose of this study fixed costs can be seen as synonymous with sunk costs, and thus, both are sources of at least limited term path dependence.

level, the lower the variable costs for the individual user will be. By contrast, the more the learning is concentrated at the farm level, the higher the fixed costs of the switch for an individual farmer. The cost structures for an individual farmer for different implementation levels are illustrated in figure 3. Furthermore, the higher the level of implementation, the stronger the protection shield will be for the farmer that his chosen technology will not be dominated by another. Thus the higher the implementation level, the stronger the grade of path dependence will be.

Figure 3. Relation of variable versus fixed costs for an individual farmer for different implementation levels



One common feature of both modern pest control technologies is that there tend to be very high fixed costs and very small variable costs. It typically involves enormous quantities of research and development (R&D) before a product or service is ready to be launched. After the R&D has been done, however, the costs of reproducing the product or information are very low.

Most of the R&D of the IPM-programmes have not yet been undertaken and it will be a long-term and difficult task because it must be very crop-specific and specific to the regional, climatic and socio-economic conditions. Such an IPM-programme may include the elaboration of cultivation techniques, the establishment of control thresholds and the evolution of predictive models. Most of these costs cannot be borne by the individual farmer but could be shared at a (a) community, (b) regional/national, (c) international or (d) global level, and thus reduce the farmers' costs.

(a) An example for the community level would be a jointly implemented scouting service by a growers' association. The cost of scouting falls if its fixed costs can be spread over many users.

(b) An example for the regional and national level is the establishment of legal requirements of quarantine to help stop a pest from spreading into endangered areas.

(c) An example for the international level is the Migratory Pests Group of the FAO monitoring the world-wide locust situation and giving timely warnings to those regions in danger of invasion.

(d) An example of globally applicable learning is the history of the parasite Aphelnus Mali. After it was discovered to control the woolly apple aphid in the U.S. and Canada it was successfully introduced in more than 25 countries for the same purpose (MCPHEE et al., 1976).

Of course, the farmer pays these costs if he buys IPM services from a private firm or if he contributes a membership fee to a collective which organises IPM-programmes. When the R&D is performed by the public sector, farmers may pay in the form of taxes. However, it is supposed that such joint contributions of the farmers affect the outcome with positive synergy.

The R&D costs of chemical control techniques have been about 5 times the expenditure on bio-control (COWAN and GUNBY, 1996, who cite NATIONAL RESEARCH COUNCIL, 1987). These costs can be considered as sunk costs, which then, according to the theory, entrench the path of CCP. The low average costs and the accumulated knowledge of chemicals at the R&D level and the farm level today serve as positive feedbacks in favour of CCP.

Two increasing returns to scale effects can be derived from the above.

Horizontally: At any level - individual, community, regional, national, international, global - the costs and knowledge of a technology must be borne before the technology is applicable. Nevertheless, once these information sources exist, any user of the level can use it. Thus, the greater the number of adopters within one level the lower the average costs.

Vertically: If the innovation takes place at the farm-level only, the individual fixed costs are very high. By contrast, the higher the level of the implementation of the technology programmes, the lower the costs for the individual farmer will be. At the same time, the protection shield of the technology becomes stronger when technology is applied at higher levels. In other words, the greater the spatial radius of adoption, the lower the average costs.

From these two implications it follows that the greater the spatial radius and the greater the number of adopters within one level, the lower the average cost for the individual user. The lower the average cost of the technology, the higher the incentive to switch to it.

1.3.3 Network externalities

KATZ and SHAPIRO (1985) ascribe to a positive network externality[5] as the feature wherein the utility that a user derives from the consumption of a good, increases with the increase in the number of other agents consuming that good. The consumption of a commodity can be seen as analogous to the use of a particular technology. Thus the value of adopting a given technology depends upon the number of other users who belong to the same network. BALMANN (1994) further distinguished between horizontal and vertical network externalities. Horizontal externalities have an effect between the members (or things) of a network whereas vertical externalities can arise from a technology which has an impact on other markets.

In the economics of interaction between the agricultural sector and the stock of natural resources, technological externalities play a crucial role (ZILBERMAN and MARRA, 1993). The use of a technology A can be subject to

? (horizontal positive) technological externalities from other users of A, and subject to

? (vertical negative) technological externalities from users of the competing technology B.

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[5] Positive network externalities have been the main focus in literature of path dependence. However, negative network externalities also exist. One example is that the higher the number of members of a network of highway users, the more they will suffer, because freeways are subject to traffic jams (LIEBOWITZ and MARGOLIS, 1994).

These inter-technological relations can provoke compatibility problems which may not allow two competing technologies to exist in the same network (FARRELL and SALONER, 1985; FARRELL and SALONER, 1986).

From the IPM point of view: The use of a natural enemy is subject to positive feedbacks from other users of the same bio-control agents because a stable population growth will be built up benefiting all users. It is thus a) a horizontal positive technological externality for the users of the IPM-technology, but at the same time, it is subject to b) vertical negative technological externalities from users of broad-spectrum insecticides or fungicides. The aerial dispersion of pesticide sprays from farms using conventional controls can upset the predator-prey matrix in such a way as to make the IPM-technology difficult to implement (COWAN and GUNBY, 1996). The advantage of the beneficial organisms of an IPM-farmer can be hindered by the following: natural enemies a) can be diminished on the field due to pest drift of nearby CCP-farmers, b) can migrate to nearby fields and can be killed by the pesticides of a farmer using CCP, c) find no appropriate habitat to develop a sustainable population because the surrounding CCP-farmers practise mono-cropping, do not rotate, or leave no fallow periods. The important point is that the activities of CCP-users can harm the IPM-users: necessary IPM-inputs become diminished, less effective or destroyed. Thus, with every CCP-user additional costs are imposed on the IPM-farmers.

From the CCP point of view: The ever increasing number of pest resistances due to pesticide application affects CCP as a positive feedback applying pressure for applications of higher dosages and at higher frequencies. This pesticide dependency is subject to the so-called chemical spiral entrenching the path of CCP (horizontal positive technological externality). As a consequence, however, CCP affects the IPM in several ways (vertical negative technological externality) as for example the higher dosages and frequencies of applications have potentially devastating implications for biological control (WAIBEL et al., 1999). This suggests that there will be a decrease in R&D and effective IPM-inputs - such as natural enemies, highly specific pesticide compounds and pheromones - available for the use in IPM-programmes.

1.3.4 Uncertainty reduction

COWAN (1991) examined the positive feedback of uncertainty reduction, which is learning about payoffs. In general the estimations about the properties and relative merits of a technology become more accurate as experience with the technology accumulates. Thus, the uncertainty about the relative merits of competing technologies may be enough to prevent a superior technology from attaining a strong market position. In particular new and relatively unknown technologies may induce uncertainty in the minds of the potential users (COWAN, 1991; COWAN and GUNBY, 1996). In contrast, the dominant technology will have the 'advantage of being better known and better understood' (ARTHUR, 1988a: 591).

While a considerable amount of experimentation of the new technology may be socially optimal, the individual risk averse (and even risk neutral) agent will have little incentive to perform it. One conclusion of this is that the market will under-supply experimentation of the new technology. However, a central authority[6] could internalise this externality by experiments and thus raise the value of the technology by reducing the uncertainty about it (COWAN, 1991).

1.3.5 Interest rate

By contrast to the endogenous factors described above, interest rate is an exogenous variable in the adoption process. Nevertheless it is of great importance in the consideration of projects in developing countries. Positive interest rates can strengthen path dependence. The initial period of lower payoffs may outweigh highly discounted future benefits. Thus, a society with a low interest rate will be more willing to invest into an ecologically sound technology with which sustainable production can be achieved in the future. By contrast, in developing countries high interest rates make the capital more expensive, and thus, the incentive to invest in IPM today and its social acceptance is reduced.

2. Case study

2.1 Development of pest control in Ghana

Previously, farmers tried to keep crop losses as low as possible, using measures such as pulling out weeds and removing egg masses. However, leaving cultivated land fallow for some years has been the most important and effective strategy to

6 COWAN (1991) explained the term 'central authority' not necessarily to be read to mean 'government', but to have agents co-ordinating actions.

avoid pest outbreaks (WORLD BANK, 1981). Nevertheless, as population pressure increased, farming systems responded by reducing fallow periods. Thus, in Ghana the introduction of pesticides was welcomed. It was assumed that pest problems could easily be eliminated with pesticides. The impact of pesticide application was visible to the farmers as pests were dying in the field. The effects were thus easier to evaluate than those of non-chemical measures. Furthermore, the low cost and subsidies of pesticides encouraged high levels of use, and a strategy of preventive practice developed in which pesticides were applied as an insurance (reduction of uncertainty) against pest attack. Soon, farmers accumulated human capital with regard to pesticide issues, like techniques of application and choice of pesticides for various crops (individual learning). At the same time, the knowledge of alternative pest control strategies diminished. Finally, the unique equilibrium was that CCP was locked-in and, when the negative effects of pesticides were noticed, it was no longer possible to re-adopt the traditional crop protection strategy. This shift of crop protection practice can be explained with the model described in figure 2a.

Today, agriculture is still the major economic sector in Ghana, accounting for a 46% share of the GDP and employing around 55% of the workforce (DER FISCHER WELTALMANACH 1999, 1998). Export performance is expected to improve via horticultural products in particular. The promotion of these crops is based on increasing productivity through the use of improved varieties and crop protection measures including the use of pesticides (LUSO CONSULT, 1996). Only chemical inputs for the production of cocoa are still subsidised. Because of agents in the cocoa sector who provide them under market value for the use in other crops, the whole pesticide market is indirectly subsidised. Government technology packages that include substantial use of and subsidies for pesticides encourage their overuse and reduce the economic incentive to use alternative pest control methods. However, a policy environment, that discourages the use of pesticides is very important and is even a prerequisite for the initiation of IPM-programmes. The horticulture sector, and especially tomatoes, is regarded as the most important sector for the use of pesticides.[7] The misuse is generally seen as very high, and due to a widespread shortage of information quite alarming. For example, on the

[7] Vegetable production usually involves a particularly intensive use of pesticides. In the USA, expenditure on pesticides by vegetable growers was nearly seven times the agricultural average in 1990 (FERNANDEZ-CORNEJO, 1996 who cites GIANESSI and PUFFER, 1992). In addition, concerns about pesticide residues are especially important with regard to vegetables, which are often consumed with little post-harvest processing (NATIONAL ACADEMY OF SCIENCES, 1987).

shelves in stores pesticides could be found next to food, and the written information about the handling of the product and its potential dangers was often very poor or even missing. Information campaigns to educate the illiterates was hardly practised at all (SCHMIDT-KALLERT, 1994).

Today, in tomato production the expenditure for pesticides amount to up to 500 US$/ha, which accounts for the highest proportion of the total costs. However, research shows that production figures per ha have been decreasing in recent years (WOLFF, 1999): There have been extreme pest outbreaks on individual plots and even throughout the entire tomato-producing area. The changes in the environmental production conditions (growing plot sizes, expanding mono-cropping, reduction in fallow periods) must be compensated for by adequate changes in cultivation methods such as rotation and criteria for land selection as well as seed selection (IPM measures). As long as this important turnaround in production method is not brought about by the farmers, the system must be defined as not sustainable, which will lead to lower income and reduction in labour opportunities in the rural areas or even collapse the tomato market. The expectations in exports under the current conditions have already diminished because high pesticide residues were identified in the fruits. In the case study the main factor identified for production loss is the pest and disease situation (WOLFF, 1999). Pest resistances accumulate in spite of the ever increasing use of pesticides.

2.2 Pushing the tomato production - in the light of the path dependence theory

To solve the problems of production loss and pesticide misuse, the Ghanaian government considered IPM to be the future guideline for crop protection in Ghana (LUSO CONSULT, 1996). The above analysis of the competing technologies suggests that there are several factors working against a switch to IPM. How IPM policy measures should be designed to overcome these factors will be discussed below.

2.2.1 Collective action in pest management

The discussion about the positive feedbacks of path dependent technologies indicates that it is only if a group of pest managers switch to the IPM-technology can it be implemented successfully. Such a collective action would reduce the transient incompatibility costs and increase the development and implementation of IPM. Collective action strategies can operate on various platforms: A basis might be the tomato growers association or one which is a direct result of public policy.

Distribution of plots - technological incompatibility: One strong obstacle affecting the shift is the technological incompatibility of the two technologies. Therefore, attention must be given to the local distribution of the farmers' plots who should adopt first. Project policy should focus on (all) farmers growing tomatoes in one area. The probability that a local cluster of farmers may successfully adopt IPM will be much higher than compared with scattered plots.

Scouting services - cost structure: Corporations will ensure better availability of IPM products - like bio-agents, predators, pheromones and resistant varieties - due to a higher market demand and effective input-buying strategies. This is particularly important for the remote communities in the rural areas in Ghana where agricultural inputs are generally more expensive. In addition, IPM services – like scouting – can be organised effectively on a higher implementation level. It is one of the most difficult inputs for IPM. Nevertheless, it is an important instrument because it leads to the decision to which pest-control strategy will be applied. As in Ghana, no thresholds exist for pests in vegetables, many data[8] will be required to assess the situation. Estimating these variables and making appropriate decisions for pest control recommendation requires high management skills. The costs of becoming skilled are mainly upfront. Most of these costs cannot be borne by the individual farmer but could be shared by a jointly implemented scouting service at the community level. Once the scouting service is established - and as such information could be non-rival, reproductive, and does not get used up in production (see ch. 1.3.2) - any user of the network can use it. The greater the number of its adopters within one network (the tomato growers association), the lower the average costs. Furthermore, the higher the level of the implementation of the scouting-programmes (if various communities of the same agro-ecological zone work together, or if co-operation takes place on an international level like in the case of the Migratory Pests Group of the FAO), the lower the cost for the individual farmer and the higher the value of adoption.

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[8] The following parameters must be estimated: 1. the relationship between the pest population and the output loss, which is expressed in terms relative to the stage of growth of (a) the pest population, (b) the natural enemies population, (c) the crop; 2. the output without the influence of the pest population; 3. the farm-gate price at the time of harvest; 4. the costs of possible control measures; 5. the efficacy of a control measure (DAXL et al., 1994).

On-farm trials – uncertainty reduction: In Ghana, IPM is a relatively new and unknown technology and there is too little experience amongst potential users to be able to make estimations about it. The uncertainty in the minds of the potential users about what the technology will do and how it will develop is thus high. The financial constraints of the tomato growers do not allow them to take the risk of investing in an unknown technology. The conclusion is that the market under-supplies experimentation. However, policy could internalise this externality by way of experiments on on-farm trials, and thus raise the expected discounted value of IPM. On-farm trials at the local level need to be large scale in order to reflect actual farming practices and to reduce outside influences (such as movements of arthropod pests and their natural enemies, or plant and disease spores). With on-farm trials, the properties and relative merits of IPM become more apparent. It will be one effective instrument for reducing growers' uncertainty about IPM, which would then enjoy the advantage of being better known and - according to the theory of positive feedback - then increase its value of adoption. An effective demonstration of a new technology is probably the most powerful form of teaching, especially in countries with low education where labels or information bulletins will never substitute demonstrations.

Co-operation with other agents: Public policy should be increasingly called for to promote co-operation between all interested parties and to ensure the transparency of the processes. Policy-makers will thus have a broad responsibility to ensure that the institutional environment is conducive to the evolution of technologies with special reference to the self-perpetuating forces. For example, IPM-users often state that they experienced difficulties in convincing credit suppliers to co-operate if they do not use the credit for pesticides but for IPM inputs (COWAN and GUNBY, 1996). Since a considerable share of the production costs was financed by credit, the IPM-programme must also involve these important agents in their IPM implementation strategy. This will lead to a reduction of uncertainty regarding the technology's institutional environment. Furthermore, co-operations may ensure a better marketing strategy for additional agricultural products, which are to be grown when, according to the IPM-programme, a crop rotation is practised.

2.2.2 Crop rotation

With crop rotation, natural factors can be used to sustainably prevent outbreaks of pest populations. It is one of the most important methods of IPM (DAXL et al.,

1994) and is seen as the most urgent component to solve the crisis in the invested tomato production systems in Ghana. However, with respect to path dependence, concerns arise because several factors will militate against the introduction of crop rotation. Suppose in the monocropping system of today a 4-year crop rotation will be implemented, then the share of the area with tomato cultivation in the community will shrink, the quantity of tomatoes produced in the community will decline and for at least three other crops, new access to the markets must be established.

Traditionally, in Ghana, most regions have a reputation for the cultivation of one particular crop. Due to the monocropping systems, the evolution of these cluster-like structures have intensified. The Ghanaian traders, often organised in cartel-like organisations, are also specialists in specific produce and have strong social relations with the producing communities. Furthermore, there are particular agreements between the traders and the urban wholesale markets whereby quotas and other market barriers make the market quite inflexible. IPM will, however, lead to a more decentralised production structure. New ties to the traders must be built up. Yet, the inflexibility of the communication facilities and the market barriers are factors which discourage the new technology. Agricultural communities which introduce new crops into their farming system must compete against the other crop growing regions and will face difficulties in gaining their traders. Establishing the necessary reputation can be a long lasting and very difficult task. Beside the financial constraints in funding these transaction costs, farmers will be uncertain whether the establishment will work. However, the greater the number of farmers who will adopt the rotation practice at the same time, the greater their power to get access to the new markets will be.

The falling tomato production level of the community may have a negative impact on the community's reputation for marketing tomatoes. This is a horizontal externality within the tomato growers' community. It explains that the utility from producing a product decreases with the falling number of other agents producing the same product in the community.[9] In addition, the shrinking tomato market of the community will increase uncertainty about the marketing possibilities, which

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[9] Of course, this is only valid if the network is defined at the community level. This formula cannot be globally applied because then gluts would decrease the producers' value of production.

already presents one of the most serious constraints identified by the farmers (WOLFF, 1999).

Three other sources of uncertainty due to the vertical externalities will be mentioned here: a) If new crops are produced, yields, product prices and input costs of these relatively unknown crops are difficult for the farmer to estimate. b) The more farmers adopt the strategy of rotation, the higher the quantity of the three other crops grown in that area. This can lead to a glut in these newly established product markets. Lower prices for these crops may be the result. c) The lack of experience with the cultivation practices of the other crops is a further source of uncertainty. When, however, the technology is adopted, the learning by doing effect will set in and farmers will improve.

With crop rotation, not only will the production method be changed on the farm level, but the whole infrastructural environment of the agricultural sector will also be affected. Horizontal (within the tomato system) and vertical externalities on the other market systems can be anticipated. The implication of the above is that the selection of crops for rotation must not only include aspects of the market value of the produce and the agro-ecological appropriateness of the crops. It must also include an analysis of the transient incompatibility costs for the market establishment which can be very high, if for example market barriers exist. It is suggested that, in order to fulfil the requirements of IPM and crop rotation in particular, to develop a farming system approach in which a range of crops will be discussed with the community since a project focusing on tomato production alone can even intensify the incentives to grow tomatoes because additional farmers then hope to gain something by cultivating tomatoes too.

3. Conclusion

IPM and CCP are technologies which reveal that path dependency also exists in the agrarian sector. The study outlines that both technologies are subject to very high fixed costs in R&D, increasing returns to scale in the production of inputs, important network effects and compatibility problems among potential users of the different technologies. Uncertainty surrounding the relative benefits of the technologies exacerbates the problems of this competition. The path dependence theory predicts, then, that a shift from the inferior technology to the superior is impeded by the inferior technology itself. The examination of several feedback mechanisms (see ch. 1.3) shows that the theory leads to satisfactory explanations of how the systems have developed. However, in the study an attempt was made not only to apply the path dependence theory up to the present day, but to examine implementation strategies which could break down the cycle of the self-reinforcing mechanisms towards the inferior technology. Policy-makers should form instruments to enable farmers to bear the transient incompatibility costs, which will inevitably result from the change of technology. This implies that collective structures of services, regulations and/or R&D should be implemented to assist the technology.[10] Such solutions are discussed for the introduction of the IPM technology in the tomato systems in Ghana.

In the light of the theory, the decision-makers may gain new insights into the mechanisms by which systems develop. This will help to elaborate implementation strategies capable of sustainably supporting their purpose. This should not be an argument in favour of a central or state-controlled economy. However, in areas where technologies have a potential negative effect on the environment, and thus future benefits are diminishing significantly, efforts must be undertaken to push the development onto the right path. At the same time, policy-makers must be aware that interventions into systems might have long-term, or even irreversible, consequences. These consequences might be desirable in the short run, but disastrous in the long run. This is particularly important for the agrarian sectors in which subsidies play an important role in the development of the system. It is hoped that the theory will be further investigated and that an improved formalisation of its nature will be implemented in future research programmes.

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[10] Another way of pushing the optimal technology is to internalise the external costs of the sub-optimal technology on its products. Several models for the internalisation of the social costs exist, such as the Pigouvian tax, the Second best solution, or the Clarke tax (ZILBERMAN and MARRA, 1993).

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Contact author:
Guido Recke
Institute of Agricultural Economics, University of Göttingen
Platz der Göttinger Sieben 5, 37073 Göttingen, Germany
phone: +(49)-551-39 95 73 fax: +(49)-551-39 48 23 email: grecke@gwdg.de