THREE ESSAYS IN DEVELOPMENT ECONOMICS: SAVINGS BEHAVIOR AND RISK; HEALTH AND PUBLIC INVESTMENTS; AND SEQUENTIAL TECHNOLOGY ADOPTION

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Dissertation Submitted to the Faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In

Economics

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July 23, 2001
Blacksburg, VA 24061

Key Words: Zimbabwe, Ethiopia, Savings, Sequential Adoption, Health

THREE ESSAYS IN DEVELOPMENT ECONOMICS: SAVINGS BEHAVIOR AND RISK; HEALTH AND PUBLIC INVESTMENTS; AND SEQUENTIAL TECHNOLOGY ADOPTION

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(ABSTRACT)

This dissertation explores household risk and savings behavior in Zimbabwe, and agricultural technology adoption, and the impact of public investments on the economy and community health in Ethiopia. The first paper analyzes changes in per capita consumption and savings behavior in Zimbabwe before and after a range of financial and weather-related shocks using comparable national income, consumption and expenditure surveys of 1990/91 and 1995/96. The empirical results show that before droughts and macroeconomic adjustments Zimbabweans used savings to smooth consumption. In contrast, risk management strategies were severely limited after the shocks; consumption tracked income more closely in the latter period. The inability to effectively address the risks arising from droughts and economy-wide structural changes implies that any subsequent economic and social uncertainty will have serious welfare consequences.

The second paper examines the interaction between public investments, community health, and productivity- and land-enhancing technology adoption decisions by farm households in Northern Ethiopia. It models technology adoption as a sequential process where the timing of choices can matter. The econometric test results indicate that the decision and intensity of technology adoption are highly correlated with the sequential nature of adoption. The most striking results concern the importance of disease—the amount of time spent sick and time spent caring for sick family members are inversely associated with both the decision and intensity of technology adoption.

Finally the third paper looks at the welfare impacts of a public water resource development project with health side effects in Tigray, Northern Ethiopia. It uses a model of a social planner to characterize the optimal implementation of such projects over time, showing how health and production are important considerations in this decision. The empirical analysis shows that the marginal net benefits of Tigray's current microdam investments are positive. The lost income households suffer from increased time away from productive activities (due to sickness) is compensated for by increased yields and market opportunities brought about through irrigated agriculture. However, it should be noted that this conclusion is based on efficiency and not equity.

ACKNOWLEDGEMENTS

First and foremost, I am eternally grateful to God for His unparalleled grace and guidance in giving me the privilege of pursuing doctoral studies. I greatly appreciate the opportunity to pursue my doctoral degree in the departments of Economics and Agricultural and Applied Economics at Virginia Polytechnic Institute and State University. Many thanks go to the faculty, students and staff of both departments for providing a supportive and academically stimulating environment.

I am highly indebted to my co-chairs, Drs. Jeffrey Alwang and Gregory S. Amacher, for their guidance, intellectual feedback, giving me the freedom to do independent research, and faith throughout the entire dissertation process. I also want to thank them for their friendship and help in other areas of my life beyond academia, especially with the challenges of being an international student. Heartfelt thanks also to Drs. Harold Alderman, Anya McGuirk, Bradford Mills and George Norton for serving on my committee and providing valuable insights for my research. Special thanks to Dr. Alderman for reading my papers and providing useful suggestions at various stages. Working as a teaching assistant for the Ph.D. econometrics course taught by Dr. McGuirk was a rewarding experience. Anya creates an excellent learning and working environment for her students and teaching assistants.

I would like to extend my appreciation to the World Health Organization and Dr. Melba Gomez for the generous financial support for my research in Ethiopia. Dr. Mitiku Haile and Mekele University College helped coordinate the data collection and created pleasant working environment during my visits to Tigray, for which I am highly grateful. I also thank the Tigray Health Bureau for invaluable advice on epidemiology of water-borne diseases, disease patterns and sampling within the Tigray region. In this regard, I would like to convey special appreciation to the openhanded farmers of Tigray for their hospitality and willingness to take considerable time off work to complete over 25 pages long survey questionnaire.

During my graduate study years at Virginia Tech, I have been blessed to have known and befriended with many remarkable people. Yonael Teklu has been a source inspiration and encouragement since my first day at Virginia Tech campus after he picked me up at the Roanoke Regional Airport. The Rancourt family (Jim, Cindy, Joshua, Kathleen, and Caleb) has kindly taken me as one of their own and showed great kindness. I am grateful for their friendship and providing me a home away from home. Special thanks to Mrs. Ann Woods, my American mother in Knoxville, where I feel at home and have a room of my own and another one for a friend. Mother Ann is a first-rate cook and made a lot of delicious dishes whenever I took off for a little breather away from school. The list of people whose kindness positively influenced my life is too long. I say thank you all from the bottom my heart.

Finally I would like to express my deepest gratitude to my parents in Ethiopia. They spent all their meager resources with no holding back in order to give me the opportunity to go to school. Without their love, unflagging support, and promising vision of the future beyond the pressing needs of the day, I would not have gone further than the Literacy Campaign.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

This dissertation explores household risk and savings behavior in Zimbabwe, and agricultural technology adoption, and the impact of public investments on the economy and community health in Ethiopia. The overall goal is to improve our understanding of the opportunities and constraints for sustainable development in Sub-Saharan Africa. The core of the dissertation consists of three individual papers presented in Chapters 2-4. The objectives of this introduction are to outline the major theme of the dissertation, to motivate the subjects and briefly explain its contributions to the existing African development literature.

1.2 Objective

The general objective of this dissertation is to examine the implications of public economic and investment policies and natural and policy-induced shocks to household and community production, health, consumption, and savings decisions in the context of Africa. The specific objectives of the three papers comprising my dissertation are as follows. The objective of the first paper (Chapter 2) is to examine the effects of drought and macroeconomic changes on household consumption and savings behavior using countrywide evidence from Zimbabwe. It analyzes changes in consumption and savings behavior before and after economic shocks and investigates the effectiveness of savings as a means of cushioning the impacts of covariate shocks. The adoption of more efficient farming practices and technologies that enhance agricultural productivity and improve environmental sustainability will be instrumental in achieving economic growth, food security and poverty alleviation objectives. The second paper (Chapter 3) examines the interaction between public investments, community health, and productivity and land-enhancing technology adoption decisions by households in northern Ethiopia. The third paper (Chapter 4) looks at the welfare impacts of public water and forest development investments with health side effects. It investigates the linkages among microdams, health, and production decisions using recently collected data from the Tigray region of Ethiopia.

1.3 Motivation

Developing countries in general and sub-Saharan Africa (SSA) countries in particular face the triple mandates of increasing economic growth, reducing poverty, and using their natural resources sustainably. The complex interlinkages among poverty, population growth, and environmental degradation posit a formidable challenge for ensuring a sustainable growth through out the region (Reardon and Vosti, 1995). With support from NGOs and multilateral official institutions such as the World Bank, several SSA countries have been engaged in programs to address poverty and revive economic development in the continent. Among such programs, macroeconomic structural adjustment initiatives, and introduction of efficiency- and productivity-enhancing technologies and projects at household levels are now quite common. For over a decade, structural adjustment programs have been implemented in SSA countries to correct policy distortions and stimulate economic recovery. However, few such programs have been sustainable. Factors such as weak micro-foundations and political infeasibility have contributed to policy reversals or failures of such programs in many SSA countries (Rich, 1997). Countries are still struggling with pervasive poverty, economic difficulties, food insecurity and environmental degradation.

Risk is an inevitable and a central fact of life in SSA countries where most agents engage in rain-fed agriculture in a drought-prone environment. The high degree of risk in Africa reflects not just the common dependence on rainfall shock, for example, but also the fact of a rain-fed, agrarian environment, with relatively isolated markets due to poor infrastructure and an undiversified economy (Udry 1994; Rosenzweig and Wolpin 1993; Rosenzweig and Binswanger 1993). For instance, droughts that simultaneously affect most households in a region put severe limitation on traditional risk management strategies such as intercropping, farm fragmentation, selling assets, etc. In order to overcome the co-variability problem, risk-sharing arrangements that cut across regions which do not experience drought simultaneously are essential; traditional risk management strategies are ill prepared to meet such demand (Gautam, *et al*., 1994). Insufficient asset entitlements also plague the economies of the SSA countries and play an important role in poverty and risk management. Formal credit and insurance institutions can pool risks across large and diversified portfolios and, in principle, offer an efficient way of overcoming regional risk covariance problems and reducing the cost of risk management.

This dissertation is motivated in part by a notion that understanding how indigenous people respond to economic crises, rather than imposing top-down remedies, should be increasingly important for sustainable recovery. Observing how agents at the micro level address poverty, risk and declining productivity may provide useful lessons for policy prescriptions. It is essential to examine how poor households respond to changes in economic circumstances, macroeconomic policies, and labor market conditions through use of locally available mechanisms. In this regard, Chapter 2 considers how Zimbabwean households' consumption and savings behavior changed due to changes in economic circumstances in the early 90's—notably after the implementation of the structural adjustment program which was followed by successive droughts. The droughts of 1992 and 1994 had devastating effects on household incomes and consumption (Alwang, *et. al.* 2000).

For more than two decades now, Ethiopia has been known around the world more for its poverty and civil problems than for prosperity and peace. Subsistence agriculture remains the mainstay of over 85 percent of the population, and the country's economic growth largely depends on improvement in this sector. Hurni (1985, 1993) as quoted by Gebre Medhin (1998) considers Ethiopia to be the most environmentally troubled country in the Sahel belt. Land degradation is manifested as soil erosion, loss of soil fertility and depth, reduced plant water availability, and deforestation. Significant productivity improvements in agriculture, and thus the economic well-being of most of the country's citizens depends, to a great extent, on adoption and sustained utilization of new yield-enhancing and resource-conserving agricultural techniques. Use of improved grain varieties, farming techniques, and conservation practices are crucial for sustainable intensification and for raising farm productivity under increasing land constraints and declining soil fertility. Yet no significant policy-related incentives exist and studies on technology adoption in Ethiopia have received little empirical attention, which is surprising considering the country's widespread food problems. Chapter 3 of this dissertation sets out to fill this gap and develops a sequential technology adoption model, whereby farmers experiment with component technologies, acquire information through social learning, and engage in learning-by-doing before fully committing to the entire technology spectrum available.

In order to address the declining agricultural productivity and improve food security and sustainability of resources, the Ethiopian government, with support from international donor organizations and official lenders has been undertaking public investments in water and tree development programs in the North, notably in the Tigray regional state. The government initiated a major rural development program there ten years ago. The program, called SAERT (Sustainable Agricultural and Environmental Rehabilitation), focused on water irrigation development through construction of 'microdams' (MUC, 1994). The presence of this irrigated water should complement agricultural practices and increase yield on irrigated lands.

However, there is concern within the World Health Organization that these new sources of standing water will invariably increase water-borne diseases. Two such diseases, malaria and shistosomiases, have historically been present in Tigray, but only seasonally during the rainy months. Standing water provides increased breeding habitat for mosquitoes, and malaria is now feared to have become a perennial problem. Incidence of shistosomiases is also expected to have increased because of the dams, as water is needed during several periods of this parasite's life cycle. Either disease will seriously affect a person's ability to work, resulting in lower productivity and more household time and resources devoted to taking care of the sick. As a result, household labor time may decrease, and any labor hours devoted to production will be less effective.

There is little work that investigates the link between water development projects, disease, and natural resources. This is surprising given the interest in bringing irrigated agriculture to arid developing country regions. It is important to understand how labor productivity, allocation of family labor time, and resource use in developing countries are affected by health. The motivation for Chapter 4 of this dissertation comes from the desire to contribute to this area of practical importance. It examines both the planning decision involving water development investments, and the empirical realization of their impacts on health, production, and other resources. The theoretical model is dynamic and assumes a social planner who is interested in choosing a public investment project scale which maximizes welfare over time, but which might impact the level of health and income of the population.

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CHAPTER 2
CHANGES IN CONSUMPTION AND SAVINGS BEHAVIOR BEFORE AND AFTER ECONOMIC SHOCKS: EVIDENCE FROM ZIMBABWE

2.1 Introduction

Individuals face numerous natural, market, and institutional risks in generating livelihoods. In recent years, a number of studies have explored the strategies by which individuals in developing countries adapt to this uncertainty. Such studies show that households generally have smoother consumption than income as well as smoother income than what a risk-neutral agent would achieve (see Zimmerman and Carter, 1996; Paxson, 1992; Deaton, 1991; Udry, 1994 and 1995; Lund, 1996).

People insulate their consumption from production and income fluctuations in different ways. They range from informal community risk sharing to participating in insurance and credit markets when such opportunities exist (e.g., Fafchamps *et. al*., 1998; Binswanger and McIntire, 1987; Bromley and Chavas, 1989; Townsend, 1995a; Udry, 1990 and 1994; Coate and Ravallion, 1993; Fafchamps, 1992; Carter, 1995; Reardon, *et. al*., 1992). They also have the option of using saving and dissaving arrangements (Paxson, 1992; Udry, 1995). Keeping cattle as an insurance substitute has longstanding importance in the economic literature on Africa (Binswanger and McIntire, 1987; Fafchamps *et. al.* 1998). Jodha (1978) and Rosenzweig and Wolpin (1993) provide evidence that livestock sales and purchases are used as part of farm households' consumption smoothing strategies.

Households may also use income diversification and remittances to mitigate risk (Binswanger and Rosenzweig, 1993; Reardon *et. al*., 1992). Individuals and communities participate in a variety of institutions (such as sharecropping and bonded labor), which sacrifice static allocative efficiency in order to manage risk. Transfers and remittances also provide implicit insurance networks among families and friends (Rosenzweig, 1988; Lucas and Stark, 1985).

The effectiveness of risk management strategies when the risky situation is common to all (such as droughts and unfavorable government policies) has not been widely investigated empirically. Even though a variety of coping strategies may be available, most of these strategies are only effective in addressing individual-specific (i.e., idiosyncratic) risks. In areas of developing countries where insurance and credit markets may not function well or do not exist, it is of interest to investigate how savings and transfers options respond to covariate economic shocks. This investigation will help determine appropriate risk management policies when governments and international institutions assist people at risk.

The objective of this study is to examine the effects of drought and macroeconomic changes on household consumption and savings behavior using two nationally representative cross sectional data sets which straddle a period of economic volatility. Specifically, the paper is intended to: (1) analyze changes in consumption and savings behavior before *and* after economic shocks; and (2) investigate the effectiveness of savings as a means of cushioning the impacts of covariate shocks.

The paper is organized as follows. Section 2 discusses a modified consumption and saving model to reflect the peculiarities of a typical developing country household. Section 3 develops the empirical model for analyzing the problem. Section 4 briefly presents background about Zimbabwe in the 1990s and describes the data source. Results and discussion are in section 5. Section 6 concludes the paper.

2.2 Household Savings and Consumption Behavior: Theory

2.2.1 Basic Household Choice Model

Define $U_t(C_t)$ as a continuously differentiable instantaneous utility function for a representative household where C_t is per capita household consumption of goods and services at time period t. Since the choice is concerned with resource allocation over time, consider a household maximizing the expected lifetime utility as of time zero

$$E\left\langle \sum_{t=0}^{T-1} (1+\theta)^{-t} U_t(C_t) \mid I_0 \right\rangle, \tag{2.1}$$

where T is the life span of the household[1]; $E(.|I_t)$ is an expectation conditional on information at time t (I_t), and θ is the rate of time preference. Thus the household is assumed to maximize the present discounted value of expected utility, conditional on information at time zero. The evolution of household assets governs the budget constraint within which intertemporal utility is maximized:

$$A_{t+1} = (A_t + Y_t - C_t)(1 + r_t), \tag{2.2}$$

where A_t is household's wealth per capita, Y_t is labor income at time t, r_t is the real interest rate. Earnings (Y_t) and the real interest rate are treated as stochastic. Households use their savings in various investment options with return r_t. Or if ($A_t + Y_t - C_t$) is negative, they borrow from credit markets or other households with positive savings.

The above basic model of intertemporal choice ignores a number of important dimensions of the livelihood strategy of a typical developing-country household. First, there may not be a clear-cut separability between capital income from asset accumulation (A_t) and labor income (Y_t). Second, we assume households can borrow and lend freely at the same discount rate. We know in practice that the credit market is not readily available in developing areas. However, for simple cases where household incomes may be determined by weather factors and capital accumulation is not an integral part of their means of livelihood, the basic model can be insightful.

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1 T can be assumed to be infinity (∞), as there are strong ties among generations in most developing countries.

Dynamic optimization can be used to solve the problem implied by (2.1) and the constraint (2.2). Optimization leads to standard Euler equations. Assume r_t is constant and that the instantaneous utility function, $U_t(C_t) = U(C_t)$ for all t. Define Ω(C) to be the derivative of U(C), then the solution to the problem becomes:

$$\left[\frac{1+\mathrm{r}}{1+\theta}\right]E_t\{\Omega(C_{t+1})\} = \Omega(C_t)\,, \qquad (2.3)$$

Equation (2.3) implies that the marginal rate of substitution between consumption in two periods should equal the expected marginal rate of transformation. The parameters r and θ control the rate at which expected marginal utility tomorrow is discounted relative to marginal utility today.

2.2.2 Permanent Income and Life Cycle Models

Both the permanent income model (Friedman, 1957) and the life cycle model (Modigliani and Brumberg 1954) are special cases of the above model. Suppose the rate of time preference (θ) is the same as the interest rate (r) and the instantaneous utility functions are quadratic so that the marginal utility functions are linear, then (2.3) becomes:

$$C_t = E_t(C_{t+1}) \qquad (2.4)$$

Equation (2.4) says that consumption is a martingale, a stochastic process whose expected value is its current value. The optimal path of consumption is such that consumption is expected to be constant over the remainder of the decision horizon. This condition, along with the budget constraint, implies that for a quadratic utility function, consumption is a linear function of expected lifetime wealth. In life cycle models, where the focus is more on age profile than uncertainty, the martingale property of consumption and saving becomes the constant consumption property of the simplest of such models. The permanent income hypothesis essentially has the same interpretation, saying that consumption is equal to permanent income, defined as the annuity value of the sum of current assets and the discounted present value of expected future earnings.

However, when people invest and save in different ways, such as through mutual reciprocity agreements, investments in human capital, etc., there is less need for saving and dissaving schemes in the way both models portray (Deaton, 1997). Including household characteristics such as age and composition in the model as factors affecting the marginal utility of consumption, in addition to consumption itself, may help address the shortcoming of the life cycle models. Let Z_t be a set of household characteristics. A version of (2.3) with such properties can be defined:

$$\Omega(C_t, Z_t) = \left[\frac{1+\mathrm{r}}{1+\theta}\right]\Omega(C_{t+1}, Z_{t+1}) \qquad (2.3')$$

Thus the age profile of consumption is determined by household characteristics and the relationship between r and θ (Ghez and Becker, 1975).

2.2.3 Household Precautionary Saving Motives

The permanent income and life cycle models do not address cases with uncertainty and when household marginal utility is not linear. Clearly, households face substantial uncertainty in most developing countries. Moreover, Deaton (1997) argues that marginal utility may well be convex for households in developing countries. This convexity has important behavioral implications. Assume that the interest rate is constant at the subjective discount rate so that equation (2.3') becomes:

$$\Omega(C_t, Z_t) = E_t\{\Omega(C_{t+1}, Z_{t+1})\} \qquad (2.5).$$

Equation (2.5) implies that if a household is risk averse, increased uncertainty, say in the form of an increase in the variance of consumption, decreases expected utility. But its effect on consumer behavior (i.e., on the Euler equation) depends on whether it affects consumer's marginal utility. Since marginal utility is linear for quadratic utility, an increase in variance of consumption has no effect on expected marginal utility, and thus no effect on behavior. As argued above, a convex marginal utility function is more plausible for a typical developing country household, and an increase in uncertainty will raise expected marginal utility. To maintain the identity in (2.5), expected future consumption must increase compared to current consumption. Thus, uncertainty leads consumers to defer consumption, to be more cautious. Higher income uncertainty and higher risk aversion lead to a lower consumption and more prudent behavior (Caballero, 1990; Kimball and Mankiw, 1989). The analysis in this paper incorporates these special features of households and tests for the implications of permanent income and life cycle models.

2.3 The Empirical Approach

Assume that consumption and savings are linear functions of permanent income (Y_{it}^P), transitory income (Y_{it}^T), income variability (VY_{it}) and a set of variables that measure the life cycle stage of a household (LC_{it}):

$$H_{it} = \phi_0 + \phi_1 Y_{it}^P + \phi_2 Y_{it}^T + \phi_3 VY_{it} + \phi_4 LC_{it} + \varepsilon_{it} \qquad (2.6)$$

$\boldsymbol{H_{it}} \equiv \{CONS_{it}, SAV_{it}\}$ is a vector of real per-capita consumption and per-capita saving instruments for household *i* in time period *t* ((*t*= 1990/91 or 1995/96), and ε_{it} is an error term. Real per-capita consumption ($CONS_{it}$) includes consumption expenditures on food, health care, schooling and others. Real savings (SAV_{it}) includes monetary savings, the net of loans taken and loans paid, purchase and sale of financial stocks, bank deposits and withdrawals, and physical asset savings (i.e., net of purchases and sales of physical assets such as land, livestock, buildings, household durables, etc.).

From the theory of permanent income, we expect the coefficient on permanent income in the $CONS_{it}$ equation (the propensity to consume out of permanent income) to be significantly higher than the coefficient on transitory income (the propensity to consume out of transitory income). For a CARA (constant absolute risk aversion) form utility function, we expect the coefficient on VY_{jt} (i.e., the impact of variability of income on consumption) to be negative for consumption and positive in the savings equations, due to precautionary savings by households. For a quadratic utility function, the coefficient on VY_{jt} will be zero for all equations.

The explanatory variables are directly obtained from the Zimbabwe Income, Consumption, and Expenditure Surveys (ICES) of 1990/91 and 1995/96, except for instrumental variables employed as a proxy for income variability. Estimating income variability (VY_{jt}) requires panel data, which do not exist in our case. Instead, VY_{it} is instrumented by a set of variables measuring the variability of regional rainfall on the grounds that more variable rainfall leads to more variable income, particularly in the predominantly agricultural economy of Zimbabwe. Standard deviations of regional and seasonal rainfall (planting, weeding and harvesting periods) over eight years are used as instruments.

The life cycle measures (LC_{it}) are variables for the number of household members in different age categories. We include the number of household members in five different age categories (less than 6 years, 6-11 years, 12-17 years, 18-64 years, greater than 64 years). Households with many young children and old members may save less since their present income is less than the annuity value of their wealth. According to the old age hypothesis, households may opt to spend on children as a substitute to saving with the view that children will take care of the parents at old age (see Paxson, 1992 and Nerlove *et. al*., 1985). The permanent and transitory incomes are derived from the Zimbabwe ICES data.

2.3.1 Permanent and Transitory Incomes

In this study, a methodology formulated by Paxson (1992) and later adapted by Alderman (1996) is employed for decomposing income into different income categories: permanent income, transitory shocks, and residual income. Paxson (1992), in her study of the savings behavior of Thai farm households, used time series information on regional rainfall in conjunction with cross-sectional data on farm household income to obtain estimates of components of household income attributed to rainfall shocks. She assumed rainfall variation produces shocks to income but has no direct effect on consumption so that the part of each household's income explained by shocks to regional rainfall serves as an explicit measure of transitory income. On the other hand, the part of household income explained by households' permanent variables (such as household members in different age, sex and education categories) serves as an explicit measure of permanent income. Finally, residual income is that part of household income unexplained by either transitory or permanent variables.

Total household income is usually estimated as a sum of household earnings from sources such as wage, farming, business, interests and rents from physical capital assets. However total income can also be derived from the outlays where it may be spent, such as consumption and savings. In the current study, since the Zimbabwe ICES does not lend itself to the first approach, household income is derived from different consumption and savings types. Let Y_{it} be a derived income for household *i* at survey period *t*. Income can be derived using the following identity:

$$Y_{it} = CONS_{it} + SAV_{it} \qquad (2.7)$$

Total household income at any given period is also made up of permanent income (denoted by Y_{it}^P) and a random transitory income component (denoted by Y_{it}^T), which can be positive, negative, or zero. Y_{it}^T represents current deviations from permanent income. Therefore households' derived income, Y_{it}, can be decomposed into permanent and transitory components:

$$Y_{it} = Y_{it}^{P} + Y_{it}^{T} \qquad (2.8)$$

Define $\mathbf{X}_{it}$ to be the set of all variables important in determining income for household *i* at time t. The variables in $\boldsymbol{X_{it}}$ may be divided into two – those affecting the permanent component of total income (denoted by $\boldsymbol{X}_{it}^{P}$) and those that affect its transitory component and income variability (denote by $\boldsymbol{X}_{it}^{T}$). Assume a household's permanent income ($\boldsymbol{Y}_{it}^{P}$) is a linear function of variables in $\boldsymbol{X}_{it}^{P}$:

$$Y_{it}^{P} = \alpha_{t}^{P} + \alpha_{P} X_{it}^{P} + \eta_{it}^{P}, \qquad (2.9)$$

where η_{it}^{P} are error terms. The parameter α_t^P represents a sector-specific variable that captures differences in income generation; α_P is a parameter vector associated with $\boldsymbol{X}_{it}^{P}$. Variables in $\boldsymbol{X}_{it}^{P}$ include family composition variables measuring the number of household members in different age, sex, and education categories, and an asset index variable. Also a sector-specific dummy variable is used to capture urban-rural differences in income generation.

In similar fashion, transitory income is defined as a linear function of $\boldsymbol{X}_{it}^{T}$, a vector of variables that mainly influence the transitory component of observed income:

$$Y_{it}^{T} = \alpha_{t}^{T} + \alpha_{T} X_{it}^{T} + \eta_{it}^{T}, \qquad (2.10)$$

where η_{it}^{T} represents error term associated with estimation of transitory income; α_t^T is a year effect, common to all households; and α_T is a parameter vector associated with

X_{it}^T. The variables used in X_{it}^T to estimate the transitory component of income are regional rainfall deviations from long-range normal precipitation. These were obtained from ten major weather stations and catchments.

2.3.2 The System of Equations

Equations (2.9) and (2.10) can be substituted into (2.6) for Y_{it}^P, and Y_{it}^T, respectively, to estimate the structural consumption and savings equations. Also we can combine equations (2.9) and (2.10) and use the identity in equation (2.8) to estimate total income:

$$Y_{it} = \alpha_t + \alpha_P X_{it}^P + \alpha_T X_{it}^T + \eta_{it} \qquad (2.11)$$

$$H_{it} = \phi_{0t} + \phi_1 \{\alpha_P X_{it}^P\} + \phi_2 \{\alpha_T X_{it}^T\} + \phi_3 VY_{it} + \phi_4 LC_{it} + \varepsilon_{it} \qquad (2.12)$$

where $\alpha_t = \alpha_t^P + \alpha_t^T$, and $\phi_{0t} = \phi_0 + \alpha_t^P \phi_1 + \alpha_t^T \phi_2$. Note that the variables in LC_{it} are collinear with $\boldsymbol{X_{it}^P}$, thus the reduced $\boldsymbol{H_{it}}$ equations can be defined as functions of just the $\boldsymbol{X_{it}}$s:

$$H_{it} = \lambda_t + \lambda_P X_{it}^P + \lambda_T X_{it}^T + \nu_{it} \ , \qquad (2.13)$$

where ν_{it} is a vector of error terms. The parameter λ_t measures the year effect, while λ_P reflects the impact of Xit^P on consumption/ savings through its effect on permanent income, and λ_T measures the impact of regional rainfall ($\boldsymbol{X_{it}^T}$) on consumption/savings through its effect on the transitory income. Equations (2.11) and (2.13) consist of three equations (income, consumption, savings) of which only two are independent since equation (2.7) has to hold. The estimates of these equations can be used to test a number of hypotheses of interest in this study.

While equation (2.13) gives reduced-form estimates of the parameters in equation (2.6), we can directly estimate them using a two-stage estimation. First, using ordinary least squares, we estimate equations (2.11). The resulting parameters can be used to decompose the total income into its estimated permanent (Y_{it}^{P}) and transitory (Y_{it}^{T}) incomes. The remainder residual income is obtained as follows:

$$\hat{Y}_{it}^{R} = Y_{it} - \hat{Y}_{it}^{P} - \hat{Y}_{it}^{T} \quad . \qquad (2.14)$$

Thus conceptually income has three components (permanent, transitory and residual). The residual component is excluded from the structural equation below since it will necessarily be correlated with the error terms.[2] Such exclusion, however, will not lead to an omitted variable problem since by design the residual component is orthogonal to the other two. We estimate the structural equation (2.6) as:

$$H_{it} = \beta_0 + \beta_1 \hat{Y}_{it}^{P} + \beta_2 \hat{Y}_{it}^{T} + \beta_3 VY_{it} + \beta_4 LC_{it} + \varsigma_{it} \qquad (2.15),$$

where ζ_{it} is a vector of error terms. Using (2.15), we can directly test the implications of permanent income hypothesis and examine changes in consumption and saving

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2 In order to see this, assume that the observed savings (H) is the sum of 'true saving' (S) and measurement error (M). Our income measure would then differ from 'true' income by M and the residual income measure would be M plus some prediction error. Both residual income and the dependent variables (i.e. H) contain M, thus introducing a correlation of errors. Note that we do not face any such problems with the predicted permanent and transitory incomes since these are fully instrumented.

behavior using parameter estimates on permanent and transitory incomes and income variability. The coefficient on the proxy for income variability (VY_{it}) can be used to see if households are risk averse and employ precautionary behavior to safeguard their consumption from income shocks. Finally we can compare all corresponding coefficients across time to investigate changes in consumption and savings behavior.

Several econometric issues need to be addressed in order to achieve consistent estimation and testing using equation (2.15). The first is the issue of measurement error typical of income and saving data in developing countries. As mentioned, the income variable was derived from consumption and savings. Moreover, instead of equating saving as a residual between income and consumption, the saving variables were directly derived from Zimbabwe ICES. This derivation avoids the spurious correlation between saving and income in the structural estimates that would result if saving was derived from the difference between income and consumption. Since income is instrumented we avoid introducing a new correlation of error terms otherwise attributed to the manner of constructing income from saving and consumption.

Finally, in order to obtain consistent estimates of the consumption and savings equations (2.15), we assume that the estimates of permanent and transitory incomes are consistent and are uncorrelated with ζ_{it}. However this procedure does not produce the correct estimates of the covariance matrix for the parameters since Y_{it}^{P}, and Y_{it}^{T} are predicted values. Therefore, for the purpose of hypothesis testing, test statistics using estimates of the asymptotic covariance matrix were employed (Newey, 1984; Pagan, 1984).

2.3.3 Tests on Savings behavior and Parameter Stability

The estimates from equations (2.11) and (2.13) together as well as the estimates of equation (2.15) can be used to test the implications of the permanent income hypothesis (PIH) and to analyze changes in savings behavior across survey years. From a PIH standpoint, we expect the propensity to consume out of the permanent income to be close to unity. In the case of equations (2.11) and (2.13), this means the impact of variables in X_{it}^{P} on $CONS_{it}$ and Y_{it} should be similar (i.e., $\lambda_p = \alpha_p$). We also test if the joint impact of X_{it}^Ts on consumption is significant. The propensity to save out of transitory income is expected to be close to unity, which in our model implies the λ_T of savings equation should be close to α_T. Put differently, the impact of rainfall variability on income should be identical to its impact on saving. The acceptance of this last test means households do in fact use saving and dissaving to smooth consumption.

The coefficients in the structural equation (2.15) can be used to directly conduct the above tests. For PIH, we can test hypotheses H_0: $\beta_1 = 1$, H_0: $\beta_2 = 0$, and H_0: $\beta_1 > \beta_2$ for the per capita real consumption equation. Failure to reject these hypotheses indicates that household consumption follows the PIH and that households use savings to reduce consumption fluctuations. Similarly, on the savings side, the reverse hypotheses are tested on total savings, i.e., H_0: $\beta_1 = 0$, H_0: $\beta_2 = 1$, and H_0: $\beta_1 < \beta_2$. Finally we can test if the coefficients on rainfall variability (a proxy for income variation) (β_4) are negative for consumption and positive for saving. Failure to reject this hypothesis indicates that households are risk averse and use precautionary savings to smooth consumption.

The second group of tests investigates if there are significant structural changes in the consumption and savings behavior. The Chow test (Chow 1983) is the most common one used for structural change. But the assumption of the same variance for error terms in both periods is crucial for the validity of Chow test. Such an assumption failed for the Zimbabwe ICES and as a result we reverted to Wald test statistic, which is distributed χ^2 (k) and takes the form $W = (b_{1990} - b_{1996})' Q^{-1} (b_{1990} - b_{1996})$, here b_{1990} and b_{1996} are parameter estimate vectors for 1990 and 1996 data respectively; k is the number of parameters being tested; and Q is the variance-covariance matrix of (b_{1990} - b_{1996}). We test the equivalency of complete parameter estimate vectors as well as subsets for important categories (such as education, asset ownership index, gender, and urban-rural variables) before and after economic shocks. We expect changes in household consumption and savings behavior across survey years because of economic shocks that occurred during the time between the two surveys.

2.4 Country Background and Data

2.4.1 Zimbabwe in the 90s

Widespread public debate has emerged about the direction and impact of economic changes in Zimbabwe during the 1990s. These changes include economic liberalization associated with the Economic Structural Adjustment Programme (ESAP), changes in governance such as decentralisation, recurring droughts, among others. ESAP was launched in December 1991, and was intended to last 5 years. ESAP was unique among adjustments in African countries in that it was not a response to a crisis per se, but represented recognition that the controlled economy of post-independent Zimbabwe was essentially unsustainable. The objectives of the program were to de-regulate the domestic economy, privatize many government-owned parastatals, de-regulate prices and wages, reduce public spending and central government's budget deficit.

Many of the ESAP reforms were not implemented as planned due to the 1992 drought, which necessitated increased public spending. During the drought, substantial portions of budgeted expenditures were reallocated to drought relief. Cuts were eventually made in public expenditures; trade and exchange rate policies were reformed; food subsidies were removed, and market liberalization was introduced in stages. Maize marketing reforms began in 1991, but were subsequently put on hold as a result of the drought. Price controls and marketing restrictions remained in place through 1994. By 1995, however, restrictions on the private movement and sale of grain were removed. The 1991-92 drought was one of the most severe in recent memories, and affected all of Southern Africa (Scoones, *et. al*. 1996). The entire economy of Zimbabwe was affected; real GDP per capita shrank by almost 12 percent in that year (Alwang*, et. al.,* 2001; CSO, 1998b). This decline was associated with the dramatic decrease in agricultural production; maize yields on all farms fell to about 1/3 of "normal" levels, and agriculture's share of total production fell from about 14 percent to below 7 percent. The drought of 1994/95 was less severe, but, coming on the heels of the earlier drought, may have led to significant increases in poverty, especially among the most vulnerable. For a variety of macro-economic and political reasons that go beyond the subject of this paper, Zimbabwe's economy has been in decline since the 1995 drought.

2.4.2 Data

The paper uses cross-sectional data from National Income Consumption and Expenditure Survey (ICES) of 1990/91 and 1995/96 from Zimbabwe. The surveys were undertaken by the Central Statistical Office (CSO) and contain data on socio-demographic characteristics, incomes, receipts from households including agriculture, consumption and other expenditures on a weekly basis, and for some durable and semi-durable items, on a monthly or yearly basis. The surveys were based on representative samples comprising all sectors of the country, i.e., the urban and the rural sectors with all their sub-sectors.

Saving can be difficult to measure, especially in developing country settings (Kozel, 1987; Paxson, 1992). Most studies of household behavior treat savings as a residual of observed expenditure and income. Income is notoriously difficult to measure. Moreover, while the Zimbabwe ICES survey covered an entire year, each recall period spanned only one month. Thus, the survey is not optimal to capture seasonal variation in income generation from agricultural and other enterprises. This motivates the use of a measure of income based on observed consumption expenditures and savings.

2.4.2.1 Consumption and Savings Measures

The household per capita consumption expenditure variable was created from an extensive list of food and non-food items from the surveys. The consumption expenditure measure includes market and non-market consumption, and consumption flows from ownership of assets. The ICES has detailed information on expenditures (market, own consumption, gifts, transfers, and payments in kind) for some 250 food-items. Since expenditures on durable goods are lumpy, we spread the value of expenditures on them over the estimated lifetime of the good in question. Expenditures on non-durable good items such as clothing, household furnishings, etc. were recorded for the month of the interview and were directly included. Total consumption was computed as the sum of consumption of food, non-durable and durable goods.

As stated above, we create the per capita saving variables from the survey data instead of defining savings as a residual between observed expenditures and observed income. Total saving is the net sum of loans taken and loans paid, purchase and sale of financial stocks, bank deposits and withdrawals, and net purchases and sales of physical assets such as land, livestock, buildings, household durable items, vehicles and other assets. SAV may be underestimated in the case of rural households whose under-the-mattress deposits are not recorded. Descriptive statistics in table 2.1 show that welfare measures (real income, real consumption, and real savings) and their cross-sectional variability had decreased after the economic shocks.

2.4.2.2 Accounting for Human and Capital Assets

Access to assets plays a determinant role in risk management and poverty alleviation. Assets affect and reflect the choice of income generating strategies and the levels of income achieved. They include land, productive capital, human capital, and livestock for direct production as well as agricultural capital. Both surveys recorded physical capital assets along with respective household access or ownership status. Ownership or access to durable and income generating assets by households may have important role in determining consumption and savings behavior. A physical asset index variable was created using the relative prices of all assets owned by households as weights. This variable is assumed to capture the role of physical assets ownership on income generation, consumption and savings decision.

Another category of household assets is human capital. Several variables were created with different age/sex/education categories to address the importance of human capital asset in molding consumption and savings behavior. Descriptive statistics show most age/sex/education variables for an average household remained about the same before and after economic shocks (table 2.1).

2.4.2.3 The Rainfall Data

Rainfall data were collected from all ten major catchment areas covering the entire country. Monthly rainfall figures for seven months (October - April) from 1989 to 1996 and normal monthly precipitation were obtained from Central Statistical Office (CSO) of Zimbabwe. October and November constitute the planting season. December and January are weeding months while the rest (February, March and April) are the main harvest months in Zimbabwe. Three weather variables representing region-specific rainfall in the three periods (planting, weeding, and harvest) of the cropping season were created. The percent deviations in periodic regional rainfall ($RPDEV_t$, $RWDEV_t$, $RHDEV_t$) from normal regional precipitation are used to estimate transitory income component of household income.

2.5 Results

Tables 2.2-2.5 contain the parameter estimates for both reduced-form and structural consumption and saving equations for 1990/91 and 1995/96. Income was also estimated for the purpose of hypotheses tests, however the results are not reported to save space. We first discuss the results of the reduced-form consumption and saving equations, (equation (2.13)) and then turn to the structural consumption and saving equation estimates shown in tables 2.4 and 2.5.

2.5.1 Consumption and Savings before and after Economic Shocks

The reduced-form consumption equations (table 2.2) for 1990/91 and 1995/96 households show that most explanatory variables have highly significant effects on consumption. The urban-rural dummy variable has a strong significance in favor of the urban sector in both years; however, the urban sector advantage diminished after the economic shocks. The asset index variable had a significant effect on consumption in both years. As anticipated, consumption increases with greater asset ownership. But, like other determinants of consumption, the return on assets fell sharply after the economic changes, indicating a worsened economic environment in the post-drought and post-macroeconomic adjustment era. The asset ownership index variable was significant in both years but its effect on consumption was higher before the economic shocks than after – in fact, its impact reduced five-fold from 1990/91 to 1995/96.

The age/sex/education variables have expected signs and significance. For male household members whose age is between 18 and 64 (the most productive age category), consumption is significantly lower for households with members with primary or lower education level. Members with secondary education or higher have positive impact on consumption. It is important to note that returns from education have fallen considerably for all age/sex groups after the macroeconomic changes and the droughts of 1992 and 1994. This is a testament to the decline in overall productivity due to macroeconomic instability evidenced in the 1990s.

Moreover, the sign and significance on household head sex variable indicate that male-headed households are better off than female headed ones. This is indicative of gender differences in income generation in developing countries and that male-headed households have a greater chance of generating more consumption goods than their female-headed counterparts. The relative impact of this gender variable remained about the same before and after the droughts and macroeconomic adjustment.

Households with many young members have lower consumption expenditures per capita. Many elderly members translate into fewer per capita consumption expenditures. The family composition variables thus follow notions of life cycle models in both years.

Most transitory rainfall variables are significant and jointly significant (see hypothesis test 1 in table 2.2). Rainfall deviations have significant unfavorable impacts on consumption expenditures. Hypothesis test 1 (p-value = 0.01 for 1990/91, p-value = 0.001 for 1995/96) shows evidence that rainfall deviations played more important role on consumption in 1995/96 than in 1990/91.

On the other hand, while positive savings accompanied rainfall deviations in 1990/91, such deviations had no significant effect in 1995/96 (table 2.3). Since rainfall variability is employed as a proxy for income variability, this result implies that household savings behavior in 1990/91 was more precautionary than it was in 1995/96. Lack of prudent response to rainfall variability following the drought and structural changes may be explained by the urgency of current needs and lack of economic resources to save for future use. Households with higher asset holdings saved more in both years. Many elderly and younger household members mean significantly negative savings, rendering some support for life-cycle models.

2.5.2 PIH and Parameter Stability Tests Using Reduced-Form Estimation

The implications of the permanent income hypothesis (PIH) on household consumption and savings behavior can be tested using the results of the reduced form equations (Tables 2.2 and 2.3). The PIH implies that the effect of transitory rainfall variables on income should be equivalent to their effect on savings and that they should have no significant impact on consumption. However, hypothesis test 1 on the consumption equation indicates that rainfall variables are both singly and jointly significant. Furthermore hypothesis test 3 (in table 2.3) showed that the rainfall deviation effect on income is not identical to its effect on savings. Thus we reject polar cases of PIH for both years. Another implication of the PIH is that saving is unrelated to permanent income. This relationship implies in our case, after controlling for life cycle variables, that permanent income variables such as asset ownership index should have zero impact on savings (i.e., should have identical effect on consumption and income). Hypothesis test 2 (in table 2.3) does not support such an assertion for both 1990/91 and 1995/96 households. The permanent income variables had significant impacts on savings in both years, contrary to the PIH implications. The hypothesis tests on the savings equations also show evidence that savings were responsive to rainfall variability in 1990/91 but not in 1995/96. The impact of rainfall variability on savings is higher for the 1990/91 households, indicating stronger deviations from the PIH for 1995/96.

Table 2.6 presents the results of parameter stability test using the Wald statistic. Wald test statistic was preferred over Chow test primarily because of lack of support for equal variances for the two periods, a critical assumption for validity of Chow tests.

The results show that overall as well as subsets of parameter estimate tests have universally rejected parameter stability. The test statistic values are extremely high and the p-values are zero for most tests, rendering strong evidence that returns to education and productive assets have changed significantly after drought and macroeconomic adjustments. This also reinforces our findings in the previous and next sections that household consumption and savings have been reduced after the economic shocks.

2.5.3 Two-Stage Consumption Estimations

The two-stage structural estimates provide us with a clear look at household savings and consumption behavior (equation 2.15) since we explicitly have permanent and transitory incomes as regressors (see tables 2.4 and 2.5).

2.5.3.1 Consumption out of permanent (YP) and transitory (YT) Incomes

The pre-drought and macroeconomic adjustment results support the implication that households consume the majority of their permanent income (about 86%). In 1990/91, households consumed a small but significant amount of their transitory income (about 48%). On the other hand, the 1995/96 data reveal that households are consuming nearly all of their transitory income (98%) and about 81% of their permanent income. Both the results of the reduced form and two-stage estimations show that Zimbabwe households' consumption behavior has changed in the 1990s. The post-drought and macroeconomic trend has been to use all sources of incomes for current consumption while pre-drought households saved the majority of their transitory income.

The empirical results show that household per-capita consumption decreases with additional young and elderly members in both survey years (table 2.4). This finding is not contrary to the old age security hypothesis that claims people depend on their children for provision when they are old. It is interesting to note that although household consumption and savings behavior changed over the 1990s, the family composition effect and its dependency structure remained intact even in the face of growing economic shocks.

Since rainfall variability is used as a proxy for income variability, we expect that if households have precautionary saving, it will have negative effect on consumption. This measure of income variability does not vary across households in the same region; caution should be taken in interpreting the results. Rainfall variability had a significant negative effect on consumption in 1990/91 but its effect was not significant in 1995/96. This result indicates precautionary behavior for 1990/91 while such precautionary behavior is not observed in the post drought and structural adjustment consumption behavior.

2.5.4 Two-Stage Saving Equations

We expect some variables that had positive impact on consumption to have the opposite effect on savings. However, it should be noted further that certain demographic and environmental variables could simultaneously increase (decrease) both consumption and savings. The results of savings (equation 2.15) estimates in table 2.5 show that households saved a significant amount of their transitory income in 1990/91. Savings out of YT is insignificant in 1995/96 than in the previous period. Households in both years saved small but significant fractions of their transitory income. The fraction saved in 1990/91 is considerably higher than that of 1995/96. Household saving increased with rainfall variability, before the drought and structural changes. Conversely, rainfall variability does not seem to have much effect on savings behavior of the 1995/96 households except that harvest period rainfall variability showed a positive effect on saving. This result shows that household precautionary savings could not be maintained as a result of severe constraints emanating from the unfavorable changes in the 1990s.

These results, along with the results from the consumption equations, show that households in the post-drought and structural adjustment period did not save as much as they did before the changes. There is increased dependence on transitory income as a source of consumption. Although we do not have evidence for a polar case of PIH, results indicate that pre-drought households used savings to mitigate income fluctuations, while such behavior was limited afterwards. Furthermore since rainfall variability is used as a proxy for income variability, these results show post drought and structural adjustment households do not manifest precautionary savings behavior while households in the earlier period saved more when their income fluctuation was higher.

2.5.5 Tests using Two-step Estimation

The results of the PIH tests using two-step estimates are statistically equivalent to the ones employing the reduced form estimates in the previous section. Hypothesis test 1 in table 2.4 shows that the propensity to consume out of permanent income is lower than unity for both years. Hypothesis test 2 indicates that propensities to consume out of permanent and transitory incomes are about the same in 1995/96 while there is evidence that the former was higher in 1990/91. The test for household precautionary savings behavior (hypothesis 3 in table 2.4) supports the notion that pre-drought and structural adjustment household consumption responded to transitory rainfall variability (a proxy for income variability). The latter period households did not respond in statistically significant fashion to income variation (p-value= 0.1778). Similar hypothesis tests for the savings equations are reported in table 5. Hypothesis 1 (i.e., the propensity to save out of transitory income is unity) is rejected for both years. Hypothesis 2 (the propensity to save out of transitory income is the same as that out of permanent income) shows some support for the PIH in 1990/91 and strong evidence against it for 1995/96. We do not have evidence to reject the hypothesis (Hypothesis 3) that rainfall variability is jointly insignificant on saving in 1995/96 (p-value of 0.2791) while we have strong evidence of significance in 1990/91 (p-value of 0.0001).

These tests indicate that changes occurred in household consumption and savings behavior after the weather and economic shocks. In 1990/91, households consumed the majority of their permanent income and saved the majority of their transitory income. The higher marginal propensity to save out of transitory income by households in this period implies that they used savings and dissavings to smooth consumption. The fact that propensities to consume out of permanent income is statistically less than one, and savings out of it are generally greater than zero indicates that a polar version of the permanent income hypothesis cannot be accepted. The post drought and structural adjustment households, however, consumed the majority of both permanent and transitory incomes. Their savings behavior had been adversely affected by recurring droughts and unfavorable economic changes. Higher income variability is associated with reduced consumption indicating prudent behavior on the part of pre-drought and pre-structural adjustment households. Household consumption and savings post-droughts and structural changes did not respond well to income variability.

2.6 Summary and Policy Implications

This paper analyzed changes in consumption and savings behavior before and after drought and macroeconomic adjustments that Zimbabwe experienced in the 1990s. It estimated the propensities to consume and save out of permanent and transitory incomes and tested the notions of permanent income hypothesis and precautionary saving motives. It examined structural changes in parameters and found that there were significant changes in return to education and assets as well as in savings and consumption behavior before and after the economic shocks. This finding has implications on the empirical validity of poverty mappings that are currently being employed to allocate transfers and inform policy design in many developing countries including Zimbabwe (see, for instance, Hentschel, *et. al* 2000). The parameter stability tests for the two periods cast serious doubt on this assumption, at least during periods of economic adjustment and natural disaster.

In addition, the analyses indicated that changes in an overall economic situation seem to translate into changes in propensities to save. To our knowledge this is the first study of its kind in Africa. This may reflect 'stock out' in which a household's ability to cushion economic shocks changes as it draws down its liquidity (Deaton, 1991; Alderman, 1996). Households facing repeated setbacks may no longer have the cash in hand or the cattle in field to offset the income shortfall. In such situation consumption more closely tracks income than when there has been sufficient time between shocks for households to replenish liquid assets.

The results show that in 1990/91 households in Zimbabwe consumed the majority of their permanent income and saved the majority of their transitory income. The higher marginal propensity to save out of transitory income by households in this period implies that they used savings to smooth consumption. However, a polar version of the permanent income hypothesis cannot be accepted. Following the drought and structural adjustment, households consumed the majority of both permanent and transitory incomes. Their savings behavior had been adversely affected by recurring drought and unfavorable economic change. Higher income variability is associated with reduced consumption indicating precautionary behavior on the part of pre-drought and pre-structural change households. Household consumption and saving in the latter period did not respond to income variability.

The findings from this study have important implications. Zimbabwean households were forced away from risk management (as manifested in the 1990/91 data) to heavy dependence on transitory income for consumption (as the results of 1995/96 show). The prolonged period of drought and macroeconomic change in the early and mid-1990s limited households' long-term ability to manage risk. Households were not able to save and use savings to buffer consumption from income shocks. Furthermore households may currently be facing credit problems due to declines in their incomes. The economy-wide decline in productivity may also constrain credit institutions. Weather risk is spatially covariant and it would be difficult, especially for rural households, to undertake arrangements that insure against drought that affects everyone in their locality simultaneously. (See, for instance, Rosenzweig and Binswanger, 1993). Our results indicate that households addressed idiosyncratic risks by saving the majority of their transitory income in 1990/91; however, they were not capable of managing covariant risks such as drought and economy-wide changes as evidenced from 1995/96 data. As a result transitory income fluctuations may have serious welfare consequences.

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Table 2.1 Variables used ($N_{90/91}$ = 14116, $N_{95/96}$ = 17527) [3].

	1990/91		1995/96	
Variable: Definition	Mean	SD	Mean	SD
RINC: real per capita income	104.082	13728.1	67.682	12021.2
RCONS: real per capita consumption	93.562	4375.8	68.153	3431.6
RSAV: real total per capita savings	10.520	12874.4	(0.471)	11634.3
RREMITR: real per capita remittances received	10.540	738.1	6.733	1233.1
RPENSION: real per capita pension income	1.044	450.4	0.981	447.2
HEAD: household head (male, female)	0.680	11.7	0.681	11.5
AGE0_5:household members age ≤ 5 years	1.280	30.2	1.104	25.8
MAL6_11: males between 6 and 11 years	0.738	22.0	0.611	19.5
MAL12_17: males between 12 and 17 Years	0.611	20.2	0.573	19.2
M18_64PE: males age b/n 18 and 64 with ≤ primary education	0.623	17.5	0.595	17.9
M18_64SE: males age b/n 18 and 64 with Secondary education	0.549	20.1	0.527	19.5
M18_64HE:males age b/n 18 and 64 with postsecondary education	0.012	3.0	0.083	7.4
FEM6_11: females between 6 and 11 years	0.738	22.2	0.624	20.0
FEM12_17: females between 12 and 17 Years	0.606	20.1	0.592	19.2
F18_64PE: females age b/n 18 and 64 with ≤ Primary education	1.028	20.1	0.943	19.8
F18_64SE: females age b/n 18 and 64 with secondary education	0.448	18.2	0.478	17.5
F18_64HE: females age b/n 18 and 64 with postsecondary education	0.004	1.7	0.059	6.5
MAL65_: elderly males (age ≥ 65 years)	0.092	7.3	0.089	7.1
FEM65_: elderly females (ages ≥ 65 years)	0.082	7.0	0.085	7.0
NATYPE: index of asset types owned	1.819	53.3	1.854	49.0
[4]CATTLE: number of cattle owned	3.605	206.9	2.961	195.6
TV: ownership of a television (yes, no)	0.114	8.0	0.194	9.7
RADIO: ownership of radio (yes, no)	0.414	12.4	0.513	12.3
UR: urban-rural dummy (1 urban, 0 rural)	0.308	11.6	0.325	11.6
CA: communal area dummy	0.554	12.5	0.533	12.3
SSCF: small scale commercial farm dummy	0.009	2.4	0.024	3.8
LSCF: large scale commercial farm dummy	0.099	7.5	0.094	7.2
RA: resettlement area dummy	0.029	4.2	0.024	3.8
RPDEV[1]: planting period rainfall deviations	11.237	567.7	(18.217)	241.4
RWDEV: weeding period rainfall deviations	8.872	394.4	(8.528)	406.3
RHDEV: harvesting period rainfall deviations	(33.238)	335.0	(58.008)	323.6

Source: Authors calculations from ICES 90/91 and 95/96 data.

1 Mean and standard deviations are across provinces, after matching each province (except Harare) with closest weather station. Harare is represented by national rainfall average. The time series data on rainfall were reported from ten weather stations.

3 The monetary variables are adjusted by 1990 Harare CPI (Consumer Price Index) to get real values from the nominal figures derived from the survey.

4 Note that cattle ownerships are only reported for rural households.

Table 2.2 Reduced-Form Real Consumption Estimates for 1990/19 and 1995/96 (Dependent variable: Per capita real consumption)

Variable	1990/91		1995/96	
	Estimate	T-value	Estimate	T-value
Constant	31.32	4.94	21.30	7.61
Urban (urban-1, rural-0)	50.87	4.08	27.84	5.84
Index of assets owned	30.21	5.28	10.39	3.84
Household head sex (male-1, female-0)	13.21	3.53	13.84	6.21
Household members age ≤ 5 years	-17.82	-12.45	-20.58	-2.38
Males between 6 and 11 years	-21.86	-11.82	-15.64	-2.75
Males between 12 and 17 years	-20.02	-10.06	-17.62	-4.01
Males age b/n 18 and 64 with ≤ primary education	-28.93	-11.2	-13.79	-8.78
Males age b/n 18 and 64 with secondary education	17.10	8.34	16.44	2.9
Males age b/n 18 and 64 with postsecondary education	66.59	5.77	31.20	9.78
Females between 6 and 11 years	-20.65	-11.28	-14.44	-5.9
Females between 12 and 17 years	-18.60	-9.27	-16.51	-3.18
Females age b/n 18 and 64 with ≤ primary education	-26.78	-11.81	-13.39	-4.78
Females age b/n 18 and 64 with secondary education	21.12	9.09	16.34	2.61
Females age b/n 18 and 64 with postsecondary education	36.79	1.96	28.66	3.97
Elderly males (age ≥ 65 years)	-35.07	-6.5	-28.60	-8.56
Elderly females (ages ≥ 65 years)	-18.28	-3.54	-17.69	-5.71
Planting period rainfall deviations	-0.18	-2.06	-3.09	-4.06
Weeding period rainfall deviations	-0.21	-1.05	-1.55	-7.08
Harvesting period rainfall deviations	-3.02	-2.69	3.41	3.47
Planting period rainfall deviations squared	-0.04	-5.43	-0.11	-4.45
Weeding period rainfall deviations squared	0.02	2.7	-0.05	-5.59
Harvesting period rainfall deviations squared	-0.04	-2.6	0.03	2.94
No. Of observations	14116		17527	
R-squared	0.367		0.287	
Hypothesis				
Test1				
Test12	6.78		9.48	
	[0.0092]		[0.0016	
Test2	2.98		56.92	
	[0.0854		[0.0000	

Note that along with coefficient estimates, t-statistics are reported instead of parameter standard errors.

1 Hypotheses tests report Chi-square (Wald test) statistics. The P-values are in the square brackets.

2 Test 1: the joint effect of rainfall is insignificant; test2: the permanent income variable, the index of asset types owned, has the same effect on consumption as on income.

Table 2.3 Reduced Form Estimates – Total Savings
(Dependent variable: Per capita real total savings)

Variable	1990/91		1995/96	
	Estimate	T-value	Estimate	T-value
Constant	7.348	1.29	-10.329	-1.99
Urban (urban-1, rural-0)	13.444	4.57	3.969	2.35
Index of assets owned	2.187	4.44	0.744	1.52
Household head sex (male-1, female-0)	2.626	2.77	0.628	1.36
Household members age ≤ 5 years	-1.085	-3.01	-0.655	-3.44
Males between 6 and 11 years	0.073	0.16	-0.566	-2.23
Males between 12 and 17 years	-0.390	-0.78	-0.652	-2.51
Males age b/n 18 and 64 with ≤ primary education	-3.605	-5.54	-0.569	-1.75
Males age b/n 18 and 64 with secondary education	-1.022	-1.98	-0.771	-2.93
Males age b/n 18 and 64 with postsecondary education	29.183	10.04	7.347	11.12
Females between 6 and 11 years	-0.107	-0.23	-0.042	-0.17
Females between 12 and 17 years	0.974	1.93	-0.177	-0.68
Females age b/n 18 and 64 with ≤ primary education	-2.785	-4.88	-0.784	-2.77
Females age b/n 18 and 64 with secondary education	0.620	1.06	-0.653	-0.5
Females age b/n 18 and 64 with postsecondary education	35.796	7.58	8.370	5.61
Elderly males (age ≥ 65 years)	-7.371	-5.42	-1.966	-2.84
Elderly females (ages ≥ 65 years)	-2.702	-2.08	-1.327	-2.07
Planting period rainfall deviations	0.048	2.11	0.104	0.66
Weeding period rainfall deviations	0.009	0.17	-0.013	-0.28
Harvesting period rainfall deviations	0.176	0.62	0.224	1.1
Planting period rainfall deviations squared	0.004	2.08	0.002	0.46
Weeding period rainfall deviations squared	0.003	1.29	0.001	0.29
Harvesting period rainfall deviations squared	0.003	0.88	0.001	0.62
No. of observations	14116		17527	
R-squared	0.20		0.26	
Hypotheses				
Test1				
Test12	0.23		3.16	
	[0.6284]		[0.0754]	
Test2	4.44		10.52	
	[0.0351]		[0.0012]	
Test3	2.30		7.47	
	[0.1190]		[0.006]	

Note that along with coefficient estimates, t-statistic is reported instead of parameter standard errors.

[1] Hypotheses tests report Chi-square (Wald test) statistics. The P-values are in the square brackets.

[2] Test 1: the joint effect of rainfall is insignificant on savings; test 2: The asset index variable has insignificant effect on savings; test 3: transitory rainfall variables have the same effect on savings as on income.

Table 2.4 Two-Step Estimation – Consumption

Variable	1990/91		1995/96	
	Estimate	T-value	Estimate	T-value
Constant	55.475	8.43	38.152	4.96
Estimated permanent income	0.861	8.98	0.811	7.45
Estimated transitory income	0.485	4.35	0.978	6.67
Household members age ≤ 5 years	-2.358	-2.05	-1.468	-2.41
Household members ages b/n 6 and 11 years	-4.355	-4.03	-0.984	-1.76
Household members ages b/n 12 and 17 years	-2.889	-2.53	-1.185	-2.09
Household members ages b/n 18 and 64 years	0.319	0.36	1.227	3.00
Household members age ≥ 65 years	-2.776	-1.08	0.769	0.61
Planting period rainfall deviations	-1.62919	-7.48	-0.004	-0.07
Weeding period rainfall deviations	0.12703	0.71	0.024	0.4
Harvesting period rainfall deviations	-0.07583	-0.87	-0.123	-1.94
No. Of Observations	14116		17527	
R-square	0.581		0.709	
Hypotheses tests[1]				
Test1[2]	18.95		44.48	
	[0.0000]		[0.0000]	
Test2	10.83		4.38	
	[0.001]		[0.0364]	
Test3	98.23		1.82	
	[0.0000]		[0.1774]	

Note that along with coefficient estimates, t-statistics are reported instead of parameter standard errors. The results are obtained by two-step procedure: first obtaining the measures of income types (YP= permanent income, YT= transitory income, YR= residual income) and finally estimating a system consisting of consumption and savings. Asymptotic variance estimates are used in testing hypotheses.

1 Hypotheses tests report Chi-square (Wald test) statistics. The P-values are in the square brackets.

2 Test 1: the propensity to consume out of permanent income is unity (i.e., $\beta_1 = 1$); test 2: the propensity to consume out of permanent income is greater than that out of transitory income (i.e., $\beta_1 = \beta_2$); test 3: the joint effect of transitory rainfall variability is insignificant (i.e., $\beta_3 = 0$).

Table 2.5 Two-step Estimation – Total Savings

Variable	1990/91		1995/96	
	Estimate	T-value	Estimat e	T-value
Constant	10.320	6.74	-9.13	-3.88
Estimated permanent income	0.046	3.45	0.11	2.34
Estimated transitory income	0.369	3.4	0.07	2.47
Household members age ≤ 5 years	1.768	1.46	1.23	6.51
Household members ages b/n 6 and 11 years	2.977	2.62	1.01	5.83
Household members ages b/n 12 and 17 years	1.130	0.94	1.02	5.82
Household members ages b/n 18 and 64 years	-0.846	-0.92	0.65	5.09
Household members age ≥ 65 years	6.295	2.32	0.28	0.72
Planting period rainfall deviations	1.584	6.91	-0.01	-0.81
Weeding period rainfall deviations	0.029	0.15	0.03	1.7
Harvesting period rainfall deviations	0.100	1.1	-0.04	-2.24
No. Of observations	14116		17527	
R-square	0.660		0.400	
Hypotheses tests[1]				
Test1[2]	3.24		11.43	
	[0.0719]		[0.0007]	
Test2	7.42		1.07	
	[0.0065]		[0.3010]	
Test3	14.55		1.28	
	[0.0001]		[0.2793]	

Note that along with coefficient estimates, t-statistics are reported instead of parameter standard errors. The results are obtained by two-step procedure: first obtaining the measures of income types (YP= permanent income, YT= transitory income, YR= residual income) and finally estimating a system consisting of consumption and savings. Asymptotic variance estimates are used for testing hypotheses.

1 Hypotheses tests report Chi-square (Wald test) statistics. The P-values are in the square brackets.

2 Test 1: the propensity to save out of transitory income is unity (i.e., β_2=1); test 2: the propensity to save out of transitory income is greater than that out of permanent income (i.e., $\beta_1 = \beta_2$); test 3: the joint effect on savings of transitory rainfall variability is insignificant (i.e., β_3=0).

Table 2.6 Results of Parameter Stability Tests—Wald test statistics

Variables	Distribution of test statistics[1]	Income		Consumption		Savings	
		Wald statistic	P-value	Wald statistic	P-value	Wald statistic	P-value
Overall test	Chi-sq (23)	8.84e+4	0.00	5.82e+3	0.00	2.71E+4	0.00
Asset index	Chi-sq (1)	2.12e+3	0.00	2.13e+3	0.00	3.88E+2	0.00
Education	Chi-sq (4)	1.14e+3	0.00	9.04e+2	0.00	3.58E+2	0.00
Rainfall	Chi-sq (6)	2.59e+3	0.00	3.34e+4	0.00	1.57E+4	0.00
Urban dummy	Chi-sq (1)	2.49	0.114	1.29e+2	0.00	9.60E+1	0.00
Gender dummy	Chi-sq (1)	0.17	0.686	4.70e-2	0.83	1.44E-1	0.70
Variance equivalence[2]	F(14993, 17504)	2.08	0.00	1.86	0.00	2.58	0.00

1 Degrees of freedom are in parenthesis.

2 The test statistic used here is: $F = \frac{s_{90}^2}{s_{96}^2} \sim F(N_{90} - k - 1, N_{96} - k - 1)$, where N_{90} and N_{96} are number of observations for 1990/91 and 19995/6 ICES, respectively; k is the number of regressors in both; (s_{90}^2, s_{96}^2) are the variances of error terms in the 1990/91 and 1995/96 regressions, respectively.

CHAPTER 3
PRODUCTIVITY AND LAND ENHANCING TECHNOLOGIES IN NORTHERN ETHIOPIA: HEALTH, PUBLIC INVESTMENTS, AND SEQUENTIAL ADOPTION

3.1 Introduction

Developing country governments face the dual tasks of increasing agricultural productivity and ensuring sustainability of resources. The usual means to achieve these objectives are through public investments with financial support from government agencies or NGOs. Often, these investments take the form of incentives to adopt improved technologies or information dissemination for technologies themselves, the argument being that growth in agricultural production should come from yield increases rather than area expansion (Eicher, 1994).

The northern Tigray region of Ethiopia provides a perfect recent example. Tigray is the most land-degraded state of Ethiopia, as most of its cultivated lands have become virtually uncultivable (Hurni, 1993). It is an arid to semi arid region characterized by subsistence farm households raising predominantly cereal and vegetable crops for local consumption and sale. Crop production has declined due to the region's recurrent drought and soil degradation. The government of Ethiopia initiated a major rural development program there ten years ago, called SAERT (Sustainable Agricultural and Environmental Rehabilitation), to correct the decline in agricultural productivity and reverse environmental degradation. SAERT specifically focuses on water resource development through the construction of microdams. These microdams are intended to bring permanent irrigated agriculture to the region. The dams are also afforested to serve as a source of fuel and to rehabilitate degraded watersheds and improve water supply.

Ethiopia's public microdam investments are similar to water-related investments in other arid countries. However, in the Tigray case, effects of these projects on local populations are different. From a technology adoption standpoint, the presence of irrigated water encourages adoption and use of technologies to complement irrigated agriculture. In addition, afforested dams provide new sources of fuelwood and should complement technologies related to resource use. But microdam creation might not always lead to widespread technology adoption or increases in agricultural productivity. The World Health Organization is concerned that these new sources of standing water have already led to increases in water-borne diseases. Two such diseases, malaria and shistosomiases, are already present in Tigray. Prior to the microdams, these infestations were seasonal. Increased habitat from microdams is now feared to have made them perennial problems (MUC, 1994). People with either disease may still be able to function in a household production role, but productivity in fields is lower and more household time is devoted caring for the sick and not working.

These diseases and their impacts on households may affect technology adoption decisions and their timing. Households may have fewer resources to invest in a full set of technologies. Or they may not have the opportunity to learn about each new technology immediately, given the financial constraints and reduced work time that increased disease brings. As a result, farmers may adopt technologies sequentially to balance the need for income with demands failing health places on their time. This important and common interaction of health and behavior is missing from the adoption literature and is missing from much of the development literature.

The purpose of this paper is to study the interaction of public investments, health and technology adoption within the Tigray region. It extends existing work by examining how characteristics of adopting households and health affect adoption, and it investigates whether timing of adoption affects the level of adoption. Most importantly, it explores the link between health and technology adoption behavior, and study how microdams and their impact on health can both complement and hinder adoption. The results will aid understanding of how public irrigation projects affect technology adoption. They should help in the future targeting of technologies and public investments designed to increase productivity, in the presence of indirect and adverse health effects.

General agricultural adoption has been studied extensively since Griliches' (1957) seminal work on adoption of hybrid corn in the USA (see, for example, Just and Zilberman; Feder *et. al*., 1985; Leathers and Smale, 1992; Feder and Umali, 1993; Caswell and Zilberman, 1986). By and large, this work focuses on adoption of a single new technology or a set of new technologies, considered as a single unit. In addition, the objective is typically to find what determines whether a particular producer adopts or rejects an innovation, or to examine the pattern of diffusion of innovations (Feder *et. al*., 1985). Commonly explored farm characteristics are farm size, land tenure, and other biophysical traits (Rahm and Huffman, 1984; Nowak 1987; Baidu-Forson, 1999). Household characteristics examined include gender, age and education of household head, family size and other demographic traits. Institutional factors such as credit constraints, availability of information and of extension services have also been examined.

There has been some work in the area of 'technology packaging, i.e., where many agricultural technologies may be made available at a given time as a package (Ryan and Subrahmanyan, 1975; Lele and Goldsmith, 1989). Byerlee and Polanco (1986) and Mann (1978) observed that farmers choose only part of a given technology package, as opposed to the whole, and farmers generally follow a stepwise process of adopting improved varieties, fertilizer, and herbicide for barley even though the components may be strongly complimentary. Leathers and Smale (1992) present a theoretical model showing it can be rational for imperfectly informed farmers to undertake sequential adoption, even when farmers are risk neutral and the entire package can be more profitable. Others have used conceptual models to identify profitability, riskiness, uncertainty, lumpiness of investment, and institutional constraints as possible explanations for sequential adoption (see Ghadim and Pannell, 1999; Ryan and Subrahmanyam, 1975; Mann, 1978).

Although this literature on technology adoption is voluminous, little work relates to the issues we study or the Ethiopian situation in general. Most previous work focuses on how characteristics of a technology, rather than the constraints facing individuals and households, affect adoption. Most previous empirical studies in developing countries have assumed that the timing of technology adoption is not important, i.e., technology alternatives are treated without regard to sequential adoption. Most importantly, no work we are aware of addresses how the timing, likelihood, and levels of technology adoption depend on the incidence of disease or health-related labor adjustments. These omissions are critical for the future packaging of technologies and water development projects in countries where water-borne diseases pose threats to the population.

3.2 The Case of Northern Ethiopia

Essential technologies for sustainable agricultural development programs may roughly be classified as *Resource Conserving* (*RC*) and *Productivity Enhancing* (*PE*). In Tigray, *PE* technologies include high yield varieties of different grain types along with in-place irrigation schemes and fertilizers while *RC* technologies comprise terraces and bands to control erosion, multipurpose trees and inter-cropping techniques. There have been few incentives for immediate adoption of either technology set. Most Tigranian farming households have few resources to finance complete adoption, and the previous communist regime was not forthcoming with information. The fact that the government leases all land to households, rather than allowing private ownership, has further compromised full adoption of all technologies.

Figure 3.1 summarizes the technology choices when timing of adoption is taken into account. We group *PE* technologies as those that increase agricultural production per a given land area. For the purpose of this study, we focus on high yield varieties (*HYV*) of different grains as the *PE* technology. Thus, heretofore we classify farmers adopting *HYV* as a '*PE*-technology' adopter. *RC* technologies, in this study, include the practice of building bands and terraces (*BT*) to control soil erosion. A farmer practicing *BT* to control soil erosion is classified as a '*RC*-technology' adopter. We begin with the premise that because of profitability, risk, and resource and information constraints, sequential adoption is central in household decisions and adoption of one technology component does not necessarily precede the other. For some farmers, the *RC* technology may be adopted first in a sequence. For others, the *PE* technology may precede the *RC* technology in the adoption decision. Others may choose to adopt everything at once or nothing at all.

All these must be treated as separate choice options. For example, a typical farmer has four choices at the beginning of technology dissemination: not to adopt any (choice 0); to adopt both (choice 1); to adopt the *RC* technology (choice 2); or to adopt the *PE* technology (choice 3). If only one component is adopted first, the next choice in the sequence is either to include the remaining component or not. Therefore, choice 4 represents those who adopted *PE* technology first and *RC* technology second; while choice 5 represents those who chose *RC* first and *PE* technology second. Both choices 4 and 5 are conditional on the previous choices.[5]

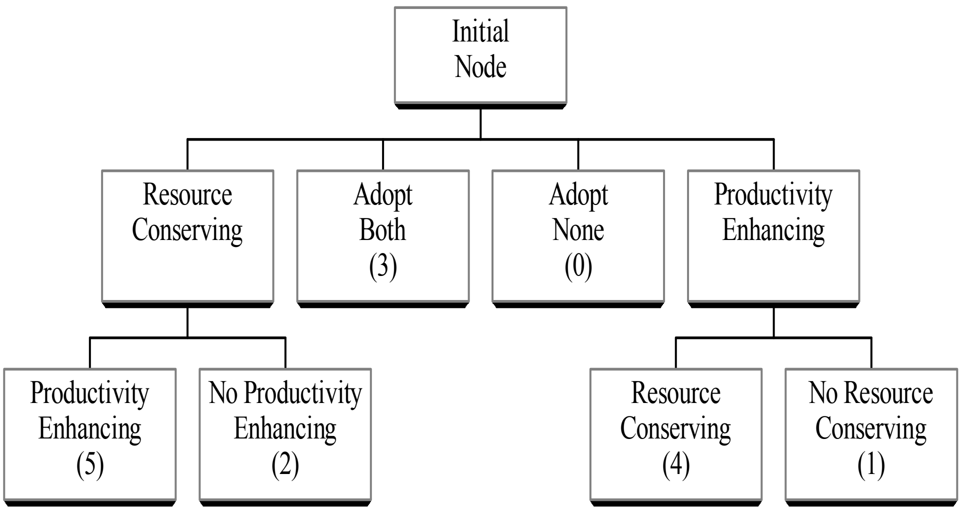

Figure 3.1: Sequential decision-making tree for a technology package with two components.6

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5 If we ignore sequential decisions and just consider the joint adoption scenario, we only have four choices: no adoption; adopt RC technology, not adopt PE; adopt PE, not adopt RC; and adopt both. This approach, in addition to ignoring possible sequencing, reduces the available choices.

6 Other choices, not shown, are possible, such as not adopting either technology in the first period and then, after observing one's neighbors, picking one or both of the technologies; or the possibility of adopting in the first stage and then rejecting in the next stage. Few households actually chose these possibilities and thus they cannot be examined econometrically in this paper.

Our premise in this paper is that characteristics of the farmer and the market lead to different adoption patterns. We now proceed to answer several questions using evidence from Tigray, such as: what explains the process of technology adoption among the Ethiopian farming community; what farm, farmer and technology characteristics are most important in determining zero adoption, delay of adoption, or sequential adoption; and how does sequencing affect the level and intensity of adoption?

3.3 A Model of Sequential Adoption

The timing of technology adoption may generate both more income for farmers and more information. Ignoring this timing may lead to inconsistent estimation of the effects of household characteristics on adoption. Inconsistency results because a static approach limits the choices available at a given point in time. For example, static models would rely on assuming a bundle of two technologies is equivalent to a single choice, whereas a sequential choice model would rely on treating the bundle as two possible choices depending on which technology was adopted first (see Figure 3.1).

Consider a farmer making technology choices over time in an uncertain environment. Assume the farmer has a planning horizon of length T and preferences are time- and state separable. Suppose there are $m+1$ different technology choices for adoption at time t. The farmer is assumed to choose one action from a set, C, containing up to $m+1$ alternatives at each period. The farmer's objective is to maximize the expected value of a sum of period-specific payoffs or utilities. Let $d_{tj} = 1$ indicate that the farmer chooses technology bundle j in t, so that $d_{tj} = 0$ means the farmer does not adopt technology j in t, $j = 0, 1, 2, \ldots, m$. Thus, the vector $\mathbf{d}_t = (d_{t1}, d_{t2}, \ldots, d_{tj})'$ describes the decision in period t,

$$\begin{aligned} &d_{tj} \in \{0,1\} \quad \forall (t,j) \in T \times C, \\ &\textstyle\sum_{j=0}^{J} d_{tj} = 1 \quad \forall t \in T. \end{aligned} \tag{3.1}$$

An action taken in period t affects the outcome, $y_t \in Y$, which arrives at the end of the period. Let $\boldsymbol{M_t}= (\boldsymbol{y_0}, y_1, \ldots, y_{t-1})$ represent the farmer's history as of the beginning of period t; it includes a vector of the farmer's initial endowment of characteristics, $\boldsymbol{y_0} \in Y_0$, and embodies the history of choices from period 1 through $t-1$. Assuming Y is a compact and finite set, the outcome y_t is either determined by the choice action vector $\boldsymbol{d_t}$ or generated according to the transition probabilities conditional on past history, $F_j(M_{t+1}|\boldsymbol{M_t})$, where $M_{t+1}=(\boldsymbol{M_t}, y_t)$. (See Hotz and Miller, 1993).

Let U_{tj} be utility associated with the choice j. Let $u_j^*(\boldsymbol{M_t}) \equiv E(U_{tj}|\boldsymbol{M_t})$ denote the conditional expectation of U_{tj}, given history M_t. Thus,

$$U_{tj} = U_j^*(M_t) + \varepsilon_{tj} \tag{3.2}$$

where the stochastic component, ε_{tj}, is conditionally independent of M_t. Let $\boldsymbol{U}^*(\boldsymbol{M_t}) = (u_0^*(\boldsymbol{M_t}),\ u_1^*(\boldsymbol{M_t}), \ldots, u_m^*(\boldsymbol{M_t}))$ and $\boldsymbol{\varepsilon}_t = (\varepsilon_{t0}, \varepsilon_{t1}, \ldots, \varepsilon_{tm})$, respectively, denote $(m+1)\times 1$ vectors of deterministic and stochastic utility components for respective choices j. We can write the distribution function of $\boldsymbol{\varepsilon_t}$ as $G(\boldsymbol{\varepsilon_t}|\boldsymbol{M_t})$ and assume it has a well-defined density function, $g(\boldsymbol{\varepsilon_t}|\boldsymbol{M_t})$.

The sequential adoption problem is then to choose $\{\mathbf{d}_t\}_{t\in T}$ to maximize the following objective function:

$$E_t\left[\sum_{t=0}^{T}\sum_{j=1}^{J} d_{tj}\left\{U_j^*(M_t) + \varepsilon_{tj}\right\}\right]. \tag{3.3}$$

Where E_t is expectation at time period t conditional on information up to time t. Following Bellman (1957) and letting $d_s^o = (d_{s0}^o, d_{s1}^o, \ldots, d_{sm}^o)$ be the optimal choice at time s, the valuation function conditional on $\boldsymbol{M_t}$ associated with choosing technology *j* in period *t+1* can be defined as:

$$V_j(M_t) = E_t\left[\sum_{s=t+1}^{T}\sum_{j=1}^{J} d_{sj}^{0}\left\{U_j^*(M_t) + \varepsilon_{sj}\right\} \middle| M_t, d_{tj} = 1\right] \qquad (3.4)$$

Thus optimal decision making implies that d^{o}_{ts}=1 if and only if:

$$s = ARGMAX_{j \in C}\left\{U_j^*(M_t) + \varepsilon_{tj} + V_j(M_t)\right\}. \qquad (3.5)$$

Conditional on history M_t, the probability a farmer chooses a technology s is therefore:

$$p_s(M_t) = \Pr ob\{s = ARGMAX_{j \in C}\left\{\left(U_j^*(M_t) + \varepsilon_{tj} + V_j(M_t)\right) \middle| M_t\right\}. \qquad (3.6)$$

Under static adoption assumptions, the technology choice is not conditioned on past choices which might affect current choices. However sequential modeling can exploit information gained from past adoption decisions. In this framework the farmer makes, at each time t, a decision involving, among other things, which technology component to adopt, based on the information set $\{\boldsymbol{M_t}\}$ and other risk and resource considerations.

As we discuss later, our data is household-based and consists of attributes of individuals making the various choices. We do not have information on specific technology attribute variables which vary among alternative choices. The appropriate econometric approach in our case is therefore to use a multinomial logit (MNL) model and explicitly incorporate the timing of adoption into the estimation. This requires increasing the adoption choice set by recognizing that the sequencing of technologies must be defined as a distinct choice.

Assume conventionally that $U_{ij}(d_{tj}, \boldsymbol{X}, \boldsymbol{M_t}, \varepsilon_t)$ is a linear function of observed exogenous variables **X** and variables characterizing the gain in information after initial adoption of one technology component, denoted by $\boldsymbol{M_t}$. U_{ij} represents the net benefit a given farmer derives from the adoption of technology choice *j*:

$$U_{ijt} = \beta M_{ijt} + \alpha' X_{it} + \varepsilon_{ijt}\ ,\ \forall i, j. \qquad (3.7)$$

Assuming the errors in (3.6), ε_{ij}, are i.i.d extreme value random variables, the probability that an alternative j is chosen can be represented by a MNL function (McFadden 1981). The test for Independence of Irrelevant Alternatives (IIA) (Hausman and McFadden 1984) can then be used to determine the importance of treating sequencing as a distinct decision within the bundle of possible technology choices. We now proceed with our empirical analysis using this approach.

3.4 Data and Descriptive Statistics

Our data come from a World Health Organization (WHO) sponsored project undertaken with cooperation of the Mekele University College of Dryland Agriculture in Tigray, Ethiopia. The project included a cross sectional survey of 800 households during one major cropping season in 1996. The survey was recall questionnaire-based and administered by enumerators trained and accompanied by the authors. Enumerators were chosen through an interview process conducted in cooperation with Mekele University College. Surveys were conducted on household heads and contained a detailed list of questions on household production, consumption, natural resource use, adoption rate and time of adoption of different agricultural and forestry technologies. They also included questions on the health impact of forest and water development investments undertaken to reverse land degradation. There were a detailed list of questions on health, number of days a household member was sick, as well as demographic information and other characteristics important to decisions and preferences. The survey sample was stratified according to proximity of villages to irrigation microdams.

Table 3.1 presents definitions of variables and selected descriptive statistics for the different adoption choices. The variables are consistent with those identified as important to adoption choices historically in the literature, i.e., family and demographic attributes of the farm household such as age or education; physical characteristics of the farm such as farm size or its topography; economic factors such as input and out prices, household income; and institutional factors such as access to extension and information services. We also include measures of the impact of health, access to natural resources and hired labor, and other variables.

Sizeable productive time is lost due to sickness, as we would expect. Household head education levels are generally very small; in fact more than 80% of the sampled household heads reported zero education. Household head education level is lowest for non-adopting households, and education level increases as adoption of more technologies increases. Malaria incidence is highest among the non-adopters, showing there indeed might be a connection between health and adoption (we investigate this formally below). Microdam age tends to reduce adoption, perhaps because the malarial infestations brought about by these dams are better developed given the length of time standing water has been in the area.

3.5 Econometric Results

3.5.1 Tests for Sequential Adoption

In this section we examine and test for sequential adoption using likelihood ratio tests to compare MNL models based on sequential and static choices, and using the test of Independence of Irrelevant Alternatives (IIA) for the MNL model that incorporates sequential adoption as explicit choices. These tests will establish whether technology timing matters to choices, thereby confirming that sequential adoption is important.

It was previously shown that if sequencing were ignored, the adoption model for the Tigray situation would include only four alternatives as choices. From Figure 3.1, this implies the additional two sequential alternatives ($j = 4,5$) are irrelevant. We can therefore undertake the IIA test by removing the sequential alternatives and re-estimating the model with the remaining four alternatives. If IIA holds, then sequencing is irrelevant and there is no gain by incorporating the timing of adoption choices. The estimated coefficients from the restricted 4-choice model, denoted by vector α_R, should then equal those from the unrestricted 6-choice model α_U under the null hypothesis. The following test statistic, H, is asymptotically Chi-square distributed with degrees of freedom equal to the number of parameters in the restricted (four choice) model:

$$\mathrm{H} = (\alpha_R - \alpha_U)'(\Theta_R - \Theta_U)^{-1}(\alpha_R - \alpha_U)\,, \qquad (3.8)$$

where Θ_R and Θ_U are variance-covariance matrices for the restricted and unrestricted coefficients, respectively.

Table 3.2 presents the results of the IIA test and its test statistic in equation (3.8). The result shows strong evidence against IIA (p-value = 0.004), indicating that sequential adoption most likely characterizes Tigray farmer behavior. As a result, the model accommodating sequential adoption will have better explanatory power over the traditional adoption model which relies on bundled technology choices and no consideration for timing.

In addition, the likelihood ratio test using the static model as the restricted model and the sequential model as the unrestricted model also shows strong evidence in support of sequential choice (p-value = 0.00001). This result is to be expected for several reasons characteristic of the region. Most Tigray farmers have few resources to finance adoption of complete packages of technologies, and agriculture risk considerations are central in the decision to use new untested technologies with uncertain outcomes.

3.5.2 Results based on Estimation of Sequential Choice Model

***Farmers with Only PE Technology Adoption*—**Table 3.2 presents the results of MNL estimation, using choices defined in Figure 3.1. For farmers who adopted only the *PE* technology package, household head age and education, distance to market and health center[7], and own and rented landholdings were all statistically significant and exhibited reasonable signs. Household head education (age) is positively (negatively) correlated with adoption of the *PE* technology. Educated households are commonly well informed and receptive, which translates to a higher likelihood of engaging in new technologies. Older heads may be more risk-averse, and less educated, and thus participate less in adoption of new technologies whose outcomes are uncertain.

Landholding, the main resource of farmers, is highly and positively significant for all adoption choices. This result comes as no surprise, since farm size figures prominently in most adoption decisions (see, for example, Dorfman, 1996; Smale and Heisey, 1993; Pitt and Sumodiningrat, 1991). What is more interesting and informative of Tigray farmers, as far as landholding is concerned, is that their adoption responsiveness increases with higher access to the rental land market. Limited access to input and output markets as well as inaccessibility to health care centers has a negative effect on adoption decisions. Perceptions of the profitability of new technologies are influenced by effective prices of inputs and outputs. Farmers living far from markets and health care facilities face high transaction and information costs that may have bearing on their adoption decisions. Also, *PE* and *RC* technologies involving water and tree development programs may also create favorable conditions for disease.

Households with good access to tree resources are less likely to engage in adoption, perhaps because the resource presence makes *RC* technologies relatively less important.

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[7] Households in our sample reported that health centers and markets are located at the same place.

Higher agricultural income tends to support adoption of *PE* technologies. Households near older microdam sites are also more likely to adopt the *PE* package than those farmers further away from microdams or near newer microdams. The older microdams have better accessibility and service potential than newer ones. Man-days of sickness had an unexpected positive sign on adoption for the *PE*-only technology. This may be a reflection that households with sick members are willing but unable to participate in the adoption of both technologies, or they may adopt the *PE* technology package to compensate for sickness-related productivity losses.

Farmers with Only RC Technology Adoption—Here we find farmers who chose to adopt only the *RC* technology have income, household labor, hired labor, landholding, availability of land for rent, and microdam age as important predictors of their decision. Income is negatively correlated with adoption of the *RC* package, implying that households with higher income would prefer to adopt both *RC* and *PE* to only *RC*. This is not surprising given that the *PE* technology requires high financial expenditures, while the *RC* technology is labor intensive. Coefficient estimates on child labor attest to this fact: the availability of child labor is positively associated with adoption of the *RC* technology (which recall includes building terraces and bands). Female labor is mostly used for home health care and other home activities. More time spent in these activities leaves households with less time for *RC* technology participation, hence the negative coefficient on female labor makes sense. Finally, higher own or rented landholding increases the likelihood of *RC* technology adoption, because building terraces or bands to protect soil erosion may lead to reduced land for cultivation.

Farmers with Simultaneous Adoption of both PE and RC Technologies—Farmers adopting both technologies simultaneously are few, as we would expect (they comprised only 9 out of 524 households included in our data). Thus, the results cannot be used to make generalized conclusions. However, Table 3.3 reveals that important predictors of adopting both technologies are landholding (both own and rental) and child labor availability.

Farmers with Sequential Adoption--Results for the sequential adoption choices, $j = 4$ and $j = 5$ in Figure 3.1, are perhaps the most revealing of all regarding factors affecting stepwise adoption. These decisions are significantly affected by more than half of the explanatory variables. Household head education level significantly and equally affects the decision of choosing *PE* followed by *RC* technology (j= *4*), as well as choosing *RC* followed by *PE* technology (j=5). Household head age has a negative effect on sequential choice $j = 4$ but has no significant effect on choice $j = 5$. Younger household heads are more willing to start adopting and learning how to use the *PE* technology and subsequently add the *RC* technology. Availability of natural resources, such as trees, discourages adoption of both sequential choices. Landholdings (both own and rental) exhibit the highest significance level of all the variables for both choices. Household male adult labor availability improves both sequential adoption choices, slightly more for choice $j = 4$. Female labor supply leads to a decline in adoption of choice $j = 5$ but has no significant effect on choice $j = 4$. Household income does not play a significant role in either sequential choice, notwithstanding the common presumption that income plays an important role in adoption.

For Tigray farmers, the factors most important to technology adoption decisions are landholding, education, access to health and market centers, access to forest and water resources, and the availability of own and hired labor. It is interesting to observe that limited access to health centers significantly discourages farmers from adopting improved technologies in four of five categories considered, including both sequential choice alternatives ($j = 1, 3, 4,$ *and* 5). This is especially important in Tigray, because microdam construction and reforestation projects are already feared to have caused serious side effects on the health of farming communities. Thus, policies targeted at health care infrastructure improvement or accessibility will clearly improve the adoption of water and tree development programs, according to our results, but they may not encourage adoption of all technologies at once given the importance of these variables to the sequential choices. Finally, education also is consistently significant in all of the adoption choices. Increasing the awareness among farmers of new technologies will likely increase adoption rate and its sustainability.

3.5.3 Marginal Effects of Explanatory Variables on Adoption Choices

The coefficient estimates for the MNL model presented in Table 3.3 do not possess the intuitive appeal of normal regression model coefficients, which directly measure the marginal effect of a unit change in each explanatory variable. For our estimates, the expected change in the probability of a particular choice being selected with respect to a unit change in an independent variable can be computed using marginal effects (see Greene, 1995).

Table 3.3 presents the marginal effects for selected variables in each sequential technology choice. Note that the sum of marginal probabilities with respect to a particular explanatory variable must equal zero, since the effects on mutually exclusive decisions must cancel out. This implies that, as an increase in a particular characteristic variable increases the adoption rate for some bundles, the adoption rate must decrease for others in the set of possible choices.

More education makes farmers more likely to adopt a combination of *RC* and *PE* technologies, but less likely to adopt only the *RC* technology. Its effect on simultaneous adoption, though positive, is insignificant. The education variable provides strong support for sequential adoption. Farmers with some education attainment are also less likely to go without adopting one or more of the technology choices: the marginal effect of the education variable is significantly negative for the probability of ‘no adoption’. This finding is in line with several previous studies which point out that successful innovation depends on farmers’ abilities to decipher and analyze information. Household head age is inversely related to likelihood of adoption of any of the technology choices except for ‘no adoption’. Older households are more likely to make ‘no adoption’ decision than younger ones.

Larger amounts of leased land are associated with increased adoption and inversely correlated with the baseline ‘no adoption’ probability. Large farm size does not significantly correlate with a higher probability of simultaneous adoption of both technologies. Sequential choices ($j = 4, 5$) are significantly and positively affected by own landholding and availability of rental land. This result reinforces our motivation noted earlier for accommodating sequential adoption. Farmers who decide to adopt a certain technology package would probably prefer to experiment with the components before fully committing to adopting the whole package. That is also exactly what the education variable's marginal effect analysis in the last paragraph tend to support.

Greater access to tree resources lowers the probability for adoption of either technology type, as it encourages the 'no adoption' decision. However, greater access to health and market centers makes farmers more likely to adopt. Households far away from market or health facilities are less likely to adopt new technologies, especially in the disease-prone areas of Tigray. Finally higher income does not lead to a higher rate of adoption for only the productivity-enhancing technology; it does not have a significant effect on combined adoption of both or of only the *RC* technology.

3.6 Sequencing and the Intensity of Adoption

Survey respondents were asked the amount of land (in *timads*) on which they practiced the new technologies after they decided to adopt them. We can now use this to examine the level of adoption chosen for each technology. For this purpose, we use the subset of farmers who adopted any combination of the technology choices (*j=1, 2, 3, 4,* and *5*), totaling 291 out of the total 524 observations.

Variables influencing the intensity of adoption can be identified by regressing the adoption level for the RC and PE technologies (i.e., the proportion of landholdings set aside for each technology) on farm and farmer characteristics, and on binary sequential choice variables (*PE-RC*, and *RC-PE*), indicating whether the farmer chose to adopt sequentially. *PE-RC* denotes farmers who adopted *PE* first and *RC* later; and *RC-PE* indicates farmers who adopted *RC* first, followed by *PE*. These binary sequential choice variables are clearly endogenous to the intensity of adoption decision. We therefore use predicted probabilities from the multinomial logit model of the previous section (P_4, P_5) as instruments for the actual binary sequential choices. The sign and significance of the coefficients will then indicate the effect of sequencing on intensity of adoption. To account for experience using the technology, we also include the number of years since the first technology in the sequence was adopted.

Table 3.4 presents the results of this instrumental variable estimation procedure applied to our data for both *RC* and *PE* technology types. Results show that sequencing has a significant effect on adoption intensities. The proportion of land allocated to the *PE* and *RC* technologies is significantly higher for farmers who adopted sequentially. Results further indicate that farmers adopting the *PE* technology first are more likely to practice the *RC* technology on a larger proportion of their landholding than those who adopted the latter first. Also farmers who adopted *RC* technology first tend to practice *PE* technology on a larger proportion of their landholding than the ones who adopted the latter first. Perhaps this is because of the complementarities inherent in using the two technologies together, or the fact that risk averse farmers will employ the first technology on less land. In either case, taking the timing of technology into account is essential in predicting intensity of adoption in Tigray, as Table 3.4 demonstrates.

Other interesting observations can also be made from the intensity regressions. While household income tends to positively impact the level of *PE* technology adoption, the size of landholding and availability of labor play critical roles in the practice of *RC* technologies. This is expected—adoption of high yielding varieties involves financial costs such as buying seeds, while building terraces and bands to control erosion is labor and land intensive.

Other factors significantly affecting the intensity of adoption are access to health care centers, microdam age, the amount of agricultural capital owned, female labor, and years of experience with the new technology. Years of experience with each technology type are directly related to the level of adoption of the respective technology, and the relationships are statistically significant. The *PE* and *RC* technologies are fundamentally and technically sound but farmers are not usually well informed at the first phases of their dissemination. However, through years of experience, it should be expected that their intensity of adoption increases. Thus, timely delivery of extension messages and demonstration plots might reduce the number of years farmers need to fully appreciate and practice a new technology on a sizeable land area.

The results also suggest that public investments in resource development such as microdams have important implications for adoption (shown before) and the level of adoption (compare Tables 3.2 and 3.4). Projects with health side effects, through their impact on household labor allocation decisions for health care and other activities, reduce the likelihood and intensity of adoption. Technologies, particularly those that complement microdams, should be packaged together with improvements in health.

3.7 Summary and Policy Implications

Land degradation and productivity decline along with rapidly growing populations pose challenges to reducing poverty in Sub-Saharan countries. These problems are not apparent anywhere more than Ethiopia. The adoption of technologies that enhance agricultural productivity and improve environmental sustainability will be instrumental to achieving economic growth and food security, and to reducing poverty. It is not surprising that there has been increased attention focused on achieving technical change in agricultural production practices and better natural resource management through diffusion of improved agricultural technologies.

The current study examines socioeconomic, environmental and cultural aspects of farmers that are important to adoption decisions. It models technology adoption as a process where timing of choices matters. The empirical tests show strong evidence in support of sequential adoption. Sequencing of technology adoption may be particularly important in Tigray, for most farming households have few resources to finance complete adoption of all technologies. The decision and intensity of technology adoption are highly correlated with the sequential nature of adoption. Both IIA and likelihood ratio tests show strong evidence for sequential adoption behavior. Even though a whole technology package may be preferable on the grounds of increased profitability, farmers in the study region tended to choose one piece of the package before adopting the other piece.

This finding has important policy implications. Government and non-governmental agencies working to improve agricultural productivity and land resource conservation should disseminate technologies in a step-wise fashion to achieve higher probabilities and greater levels of their adoption. It may be the case that farmers are not willing to adopt the entire package at the outset of technology dissemination due to lack of sufficient information and awareness about the technology package. Thus, an efficient extension mechanism should include demonstration plots and participation of farmers in the innovation development process; these will both quicken their adoption response and ensure greater scale of usage.

The most striking aspect of the study, and one not raised in the literature, is the importance of public investments and corresponding changes in health to adoption behavior. Changes in the health induced by microdam construction have significantly reduced both the likelihood and intensity of technology adoption. Landholding (both own and rented), household head age and education level, access to market and health care centers, the age of and distance to microdams, and labor availability (adult, child and hired) were all found to significantly affect adoption probabilities, adoption levels, and the probability of sequencing choices.

Although it is missing from the adoption literature, the empirical results suggest investments in health are critical to adoption behavior. It finds that improving access to health care centers will have positive impacts on adoption of both yield- and land-enhancing technologies. Health care provision is especially critical in Tigray, because malaria and schistosomiasis are now thought to be perennial problems due to microdam construction and shade-producing reforestation projects made during the past decade. Interestingly, older and nearer microdams are correlated with higher adoption levels, as sick farmers may be looking for other ways to increase productivity and compensate for loss of productive time (if they can afford to). However, the positive effect on adoption of productivity enhancing technologies, due to irrigation opportunities made possible by microdams, is partially offset by the negative health side effects. Farmers are willing to utilize new technologies only provided that health care centers are within close proximity, perhaps because less household financial and time resources would then be needed to manage declines in health.

Educated and younger household heads are more likely to adopt new technologies than older and less educated ones. Thus, new innovation dissemination should target younger households. Landholding was found to be a very important determinant for adoption and sequencing in our study area. The availability of land for rent also played a positive role in adoption. Household labor, as well as the availability of hired labor, encourages farmers to engage in adoption. Thus, institutional and governmental steps to improve land and labor markets will likely increase adoption, thus helping to enhance productivity and resource conservation.

3.8 References

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Table 3.1 Variables used and their descriptive Statistics by adoption category

Variable	Mean	Sd	Mean	Sd	Mean	Sd
Sequential adoption category	J=0(231[a])		J=1(113)		J=2(108)	
Household size	4.9	2.2	5.4	2.3	5.0	2.1
Household head education	0.4	1.3	1.0	1.8	0.5	1.3
Household head age	48.3	14.6	45.9	14.6	47.8	14.2
Microdam age	4.9	2.9	5.0	3.4	6.6	3.0
Animal unit	3.2	3.1	3.7	3.6	3.9	4.1
Household own trees	71.4	232	78.2	200	31.1	104
Government forest	36.0	122	29.2	171	9.2	30.1
Malaria incidence dummy	0.2	0.4	0.5	0.5	0.2	0.4
Own landholding (no. Of timads[8])	4.2	2.3	4.6	2.4	4.9	2.3
Rented landholding	1.0	2.1	1.2	2.3	1.6	2.9
Distance to health center	8.7	5.0	4.8	3.7	10.6	3.0
Distance, fuelwood collection area	14.4	21.8	10.8	17.7	14.1	15.3
Adult male labor supply	58.2	63.9	71.6	68.9	59.9	53.1
Adult female labor supply	128	108	118	91.5	99.5	71.7
Household time sick	25.7	48.8	50.9	72.7	16.6	36.7
Health care-for- others time	0.6	3.0	2.9	16.6	0.4	2.1
Off-farm wage labor supply	19.5	37.5	12.1	32.0	5.9	22.2
Hired labor demand	8.6	24.8	19.1	56.0	3.7	14.1
Child labor	64.5	92.3	69.7	86.3	91.1	108
Household total income	964	709	1220	949	883	642
Income from off-farm wage labor	68.4	198	45.3	164	20.3	90.1
Sequential adoption category		J=3(9)		J=4(25)		J=5(38)
Household size	6.3	2.3	5.6	2.1	5.3	2.2
Household head education	0.6	1.1	1.0	1.7	1.1	1.9
Household head age	41.9	14.1	42.4	13.1	46.6	14.5
Microdam age	3.7	3.0	4.1	1.8	4.8	2.9
Animal unit	5.4	3.5	4.3	3.0	4.4	4.5
Household own trees	33.4	44.1	50.0	63.7	55.7	97.6
Government forest	4.4	13.3	21.5	40.3	14.6	35.2
Malaria incidence dummy	0.1	0.3	0.6	0.5	0.5	0.5
Own landholding	7.5	2.5	6.3	2.2	5.5	2.6
Rented landholding	3.3	4.6	3.5	7.0	2.6	2.8
Distance to health center	6.2	4.5	6.1	3.9	6.7	4.1
Distance, fuelwood collection area	39.8	32.3	21.2	24.3	18.0	24.6
Adult male labor supply	90.4	148	125	95.9	101	69.9
Adult female labor supply	86.8	62.4	102	88.3	86.7	77.8
Household time sick	24.8	47.1	46.5	65.0	28.7	30.8
Health care-for- others time	6.6	15.6	5.4	10.5	3.3	7.9
Off-farm wage labor supply	19.0	57.0	3.5	12.5	6.1	20.9
Hired labor demand	12.4	17.5	5.3	12.9	4.4	9.5
Child labor	170	51.1	83.2	111	102	104
Household total income	1597	870	1250	736	1047	635
Income from off-farm wage labor	63.4	118	43.2	97.2	38.5	92.8

a The number of households in each category is in parenthesis.

8 *Timad* is a traditional measure of farmland size in Ethiopia. 1 timad is roughly equal to 0.5 hectare.

Table 3.2 Estimates of multinomial logit model based on sequencing of choices

Variable	Sequential Adoption Category			
	(J=1)a		(J=2)	
	Estimate	T-value	Estimate	T-value
Constant	-1.451E+00	-1.206	-7.915E-01	-0.807
Household head education	2.018E-01	1.916	6.802E-02	0.594
Household head age	-3.644E-02	-2.971	-8.442E-03	-0.824
Micro dam age	1.414E-01	2.306	3.667E-01	6.431
Household own tree holding	-2.119E-03	-1.619	-2.177E-03	-1.870
Animal unit	-5.287e-02	-0.921	-2.185e-02	-0.423
Distance to health center	-2.555E-01	-6.158	1.933E-02	0.542
Own landholding	1.173E-01	1.550	2.262E-01	3.020
Rental landholding	-4.753E-03	-0.055	2.885E-01	3.746
Hired labor employed	5.504E-03	1.420	-1.756E-02	-2.012
Adult male labor supply	3.178E-03	1.209	-9.589E-04	-0.324
Adult female labor supply	2.322E-04	0.154	-6.494E-03	-3.500
Child labor supply	-1.075E-04	-0.059	3.143E-03	1.927
Household time sick	1.013E-02	3.362	-3.882E-03	-1.051
Household income	3.888E-01	2.316	-3.352E-01	-2.577
Number of Observations	113		108	

[a] (J = 1) ≡ Farmers with adoption of Productivity-Enhancing (PC) technology only

(J = 2) ≡ Farmers with adoption of Resource-Conserving (RC) technology only

Table 3.2 Estimates of multinomial logit model based on sequencing of choices (cont'd…)

Variable	Sequential Adoption Category					
	(J = 3)[a]		(J = 4)		(J = 5)	
	Estimate	T-value	Estimate	T-value	Estimate	T-value
Constant	-4.900E+00	-1.090	-2.683E+00	-1.136	-2.48E+00	-2.594
Household head education	2.005E-01	0.735	3.306E-01	2.116	3.72E-01	2.919
Household head age	-4.272E-02	-1.147	-4.706E-02	-2.090	9.93E-04	0.065
Micro dam age	1.658E-03	0.006	1.020E-01	0.771	2.24E-01	2.604
Household own tree holding	-9.916E-03	-1.151	-4.391E-03	-1.859	-3.08E-03	-2.01
Animal unit	-1.429e-01	-1.015	-1.567e-01	-1.669	-4.97e-02	-0.691
Distance to health center	-2.279E-01	-2.018	-2.581E-01	-3.600	-2.15E-01	-4.041
Own landholding	5.367E-01	2.966	4.726E-01	4.039	3.66E-01	3.786
Rental landholding	3.549E-01	2.946	3.201E-01	3.521	3.36E-01	3.939
Hired labor employed	-1.451E-02	-0.567	-3.101E-02	-1.552	-3.34E-02	-1.961
Adult male labor supply	2.037E-03	0.316	1.220E-02	3.277	7.48E-03	2.314
Adult female labor supply	-8.978E-03	-1.647	-4.397E-03	-1.491	-7.77E-03	-2.974
Child labor supply	8.897E-03	2.479	7.632E-04	0.277	3.36E-03	1.612
Household time sick	4.340E-04	0.042	6.802E-03	1.341	-2.55E-03	-0.531
Household income	3.891E-01	0.618	1.789E-01	0.535	5.63E-04	1.516
Number of Observations	9		25		38	

Sequential choice model:
log-l function = -505.4138, restricted log-l = -680.8276,
chi-squared = 350.8276
Non-sequential choice model:
log-l function = -448.4989, restricted log-l = -611.3828,
chisquared= 325.7678

Likelihood ratio test (sequential vs non-sequential choice model):
chi-squared = 113.8299, p-value < 0.0001

Iia test: chi-squared (15) = 32.524, p-value < 0.005

[a] (J = 3) ≡ Farmers who adopted both *RC* and *PE* technologies simultaneously

(J = 4) ≡ Farmers who adopted *PE* technology followed by *RC* technology

(J = 5) ≡ Farmers who adopted *RC* technology followed by *PE* technology

Table 3.3 Marginal choice probabilities

Variable		T-value		T-value
Marginal Effects on Prob[J = 0]			Marginal Effects on Prob[J = 1]	
Household head education	-4.74E-02	-2.127	2.16E-02	1.703
Household head age	4.54E-03	2.252	-4.64E-03	-2.958
Micro dam age	-6.37E-02	-5.193	7.66E-03	1.011
Household tree holding	6.12E-04	2.814	-1.79E-04	-1.102
Distance to health center	3.17E-02	4.716	-3.19E-02	-6.324
Own land holding	-6.50E-02	-4.717	4.24E-03	0.45
Rental land holding	-4.63E-02	-3.01	-2.45E-02	-2.296
Male adult labor supply	-3.14E-04	-0.625	3.02E-04	0.896
Female adult labor supply	9.51E-04	3.119	4.20E-04	2.118
Child labor supply	-4.57E-04	-1.383	-2.67E-04	-1.119
Household time sick	-5.03E-04	-0.75	1.47E-03	3.969
Household income	7.27E-05	1.436	1.22E-04	4.097
Marginal Effects on Prob[J = 2]			Marginal Effects on Prob[J = 3]	
Household head education	-2.00E-03	-0.122	8.18E-04	0.485
Household head age	5.55E-04	0.37	-1.93E-04	-0.799
Micro dam age	5.00E-02	6.15	-7.06E-04	-0.447
Household tree holding	-1.59E-04	-0.877	-5.22E-05	-1.039
Distance to health center	1.69E-02	3.362	-9.77E-04	-1.107
Own land holding	3.02E-02	2.852	2.78E-03	1.469
Rental land holding	4.47E-02	4.035	1.80E-03	1.324
Male adult labor supply	-7.30E-04	-1.727	-8.00E-07	-0.022
Female adult labor supply	-8.61E-04	-3.181	-4.11E-05	-1.063
Child labor supply	5.09E-04	2.161	4.95E-05	1.42
Household time sick	-8.87E-04	-1.676	-3.07E-06	-0.05
Household income	-1.64E-04	-3.557	1.52E-06	0.473
Marginal Effects on Prob[J = 4]			Marginal Effects on Prob[J = 5]	
Household head education	7.48E-03	1.827	1.95E-02	2.559
Household head age	-9.23E-04	-1.705	6.56E-04	0.694
Micro dam age	-4.73E-04	-0.141	7.20E-03	1.414
Household tree holding	-8.85E-05	-1.479	-1.34E-04	-1.419
Distance to health center	-4.95E-03	-2.475	-1.07E-02	-3.362
Own land holding	1.08E-02	2.815	1.69E-02	2.799
Rental land holding	7.05E-03	2.297	1.72E-02	3.118
Male adult labor supply	2.67E-04	2.415	4.76E-04	2.377
Female adult labor supply	-5.53E-05	-0.761	-4.13E-04	-2.637
Child labor supply	-6.54E-06	-0.098	1.73E-04	1.412
Household time sick	1.62E-04	1.28	-2.41E-04	-0.85
Household income	-2.66E-06	-0.272	-2.94E-05	-1.305

Table 3.4 Intensity of *RC* and *PE* technology adoption—Instrumental variable estimation using predicted probabilities as instruments for sequential adoption binary variables

Variable	*Timads* of land used per total landholding (PE technology)		*Timads* of land used per total landholding (RC technology)	
	Coefficient	T-value	Coefficient	T-value
Constant	1.554E-01	0.611	-7.600E-01	-1.650
P_4	9.196E-01	2.524	2.019E+00	4.659
P_5	1.282E+00	5.613	9.819E-01	2.105
PE year#	1.883E-01	5.341	5.033E-02	2.590
RC year	1.176E-02	0.689	1.619E-01	3.691
Household income	5.847E-02	1.748	-9.865E-02	-1.726
Intervention village dummy	9.669E-02	1.018	5.057E-01	3.587
Household head education	3.538E-02	0.950	-6.812E-02	-1.546
Household head sex	-2.925E-03	-1.002	1.252E-01	0.796
Household head age	-2.853E-01	-1.160	-2.672E-03	-0.588
Distance to health center	-4.833E-02	-3.599	-6.504E-02	-4.364
Male labor supply	9.832E-05	0.099	4.903E-04	0.391
Female labor supply	3.635E-05	0.084	-1.996E-03	-3.739
Child labor supply	3.778E-04	0.760	1.259E-03	1.307
Household sick time	7.083E-04	0.655	4.257E-04	0.294
Microdam age	6.379E-03	0.171	1.178E-01	5.004
Distance to microdam	-3.358E-03	-0.156	1.349E-02	0.511
Own landholding	3.351E-02	1.115	1.238E-01	2.846
Household own tree holding	-4.394E-04	-1.524	-5.231E-04	-0.767
Animal unit	5.560E-02	2.586	4.232E-02	1.794
N	291		291	
R^2	0.468		0.449	
Adjusted R^2	0.445		0.424	
Log likelihood	-678.554		-776.520	
Restricted Log likelihood	-820.732		-910.785	

PE year and *RC* year are years since *PE* and *RC* were adopted, respectively.

CHAPTER 4
ECONOMIC ANALYSIS OF DEVELOPMENT PROJECTS WITH HEALTH SIDE EFFECTS: EVIDENCE FROM NORTHERN ETHIOPIA

4.1. Introduction

Ethiopia is currently losing natural resources at alarming rates. This is especially true in the northern regions, where famine and lack of drinking and irrigation water are common. The increasing loss of topsoil and nutrients brought about by archaic agriculture and erosion have resulted in steady declines in land and labor productivity, coupled with high population density, famine, food insecurity and dependence on food aid (Shiferaw and Holden, 2000a, 2000b). The Ethiopian government, with financial assistance from several NGOs, recently implemented a program to establish sustainable agricultural development in Tigray. The main element of this program is construction of pooled areas of water called microdams. Microdams are intended to help bring permanent irrigated water to Tigray agriculture. The dam areas are also afforested to serve as a wood source, freeing villagers to use agricultural residues as a natural fertilizer instead of a means for heating and cooking.

There are already signs that microdams are leading to increased agricultural production. Villagers are enjoying more than one cropping season per year and increased yields (MUC, 1994). Villagers living in the vicinity of the projects are also using the dams for water and fuelwood, thus lessening the demand on their time for foraging. This has further freed labor time for agriculture and other productive activities. It is hoped the increased access to fuelwood and the resulting ability to leave agricultural residues in the field will replenish soil fertility and further increase agricultural productivity. Other productivity-enhancing aspects of the afforestation projects include protection of soil from wind and water erosion (Gebre Medhin, 1998).

Unfortunately, microdams are not without side effects to the population. Environmental and agricultural development programs have direct and spillover effects on household time allocation for various activities, health, nutritional status and profits from farm operations. Tigray has historically been free of water-borne disease during the dry months. It is now feared by many agencies, notably the World Health Organization, that permanent standing water provided by microdams and resulting irrigation ditches could increase or make permanent water-borne diseases, specifically malaria and schistosomiasis. Both diseases are debilitating and, if contracted, affect villagers' ability to work productively, or even to work at all. If extensive transmission of disease to the population occurs, many villagers will be forced to reallocate labor and work less, either because they cannot function or because they must stay home and care for sick household members. Working less throughout planting, weeding, and harvesting seasons, or having less time for fuel collection, will likely decrease income and welfare. There may also be decreases in income from increased health care expenditures or increased time spent visiting health facilities. A recent contingent valuation study in Tigray by Lampietti (1999) indicates that malaria risk is perceived to be widespread in the region and households consider it to be a serious health problem.

There is also a link between microdams, health, and natural resource stocks. Microdam reforestation projects were initially intended to reduce exploitation of remaining government forests for fuel. But if health of the population weakens, then higher forest exploitation could result due to increased heating needs. Moreover, a reduction in health may reduce the ability of individuals to deforest distant forests, either because of the decrease in available labor time or the inability to travel long distances. Increased time spent caring for sick family members also discourages collection on more distant forestlands. Thus, poorer health in the population may increase exploitation of less distant forests where access is easier. These sites would almost certainly involve the reforested microdam areas, which are typically located near villages. Increased pressure on microdams for fuelwood would of course eventually decrease water yield and erosion protection, leading to decreased productivity and income.

There is little work we are aware of that investigates what these linkages are, or how impacts should be balanced when allocating water and fuel development efforts. This is surprising despite the clear connection between water development projects, disease, and natural resources, and despite the importance of bringing irrigated agriculture to arid developing country regions. Grossman (1972a, b) formulated the first model that established the connection between health and economic decisions, showing that individuals invest in health production until the marginal cost of health production equaled the marginal benefits of improved health status. An individual's health status was assumed to affect utility both indirectly, through raising labor income and thus increasing the choice set, and directly by assuming that individuals value good health per se. Since Grossman, several economists (e.g. Wagstaff 1986, 1993; Pohlmeier and Ulrich 1995; Johansson and Lofgren 1995; Gerdtham and Johannesson 1997) have carried out empirical work on the demand for health. Most of these models have been applied to wage-earning individuals notably in the developed countries. There is no work we are aware of that establishes how health is an important side effect of development projects. Similarly, there is little work that shows how labor productivity, allocation of family labor time, and resource use for non-wage earning self-employed farmers are affected by health in developing economies. Audilert (1986) investigated the effect of health status on the productivity of agricultural workers, particularly non-wage-earning rice-growing peasants in Cameroon. He showed that a worker's health status significantly influenced paddy output through a production function analysis. Pitt and Rosenzweig (1986) and others examine how agricultural prices and health programs affect the health, nutritional status, and farm profitability using Indonesian data and a farm household model. However, no studies we are aware of looked at the linkage between health, farm productivity and land resource (such as forest) exploitation.

The purpose of this paper is to investigate both the planning decision involving water development investments, and the empirical realization of their impacts on health, production, and forest stocks. The theoretical model is dynamic and assumes a social planner who is interested in choosing a public investment project scale which maximizes welfare over time, but which might impact the level of health and income of the population. The necessary conditions establish rules under which such investments are optimal. The rules depend critically on how investments impact health and forest stocks. It investigates the decision using data from Tigray on production, health, and microdam investments. The empirical model establishes and evaluates the link between microdams, health, and natural resource exploitation.

The results here are useful in determining whether the microdam projects undertaken over the last decade in Ethiopia are efficient in terms of marginal net benefits provided to the population. The model and analysis should therefore help policy makers develop a better understanding of the interrelationships among community health, public resource use, and economic development programs such as microdam construction for water supply and irrigation. The theoretical model enables us to decompose project costs and benefits into several meaningful components, which will ultimately allow us to formulate policy recommendations on the relative merits of development projects such as microdams. The approach and results developed in this paper may have applications in other cases where governments are considering water-related public investments in resource-degraded countries.

4.2 Theoretical Model

We now turn to a theory explaining the relationships among public investments, resource use, and health. Assume there is a social planner who is interested in developing a microdam water investment project that includes afforesting an area surrounding the dam (we will use the term microdam and 'development project' interchangeably). Assume the investment is planned to continue for a definite number of years. Without loss of generality, we can let the planning horizon include project management post construction. Thus periods over time represent the number of years in the project cycle, and decisions made during one period are not independent of the decisions made in the previous period or decisions to be made in the next period. Since the development project will obviously have an impact well after it phases out, we also assume conventionally that there is some residual effect (i.e., a salvage value) of the project which is realized at the end of the project cycle.

Let t_0 be the time period when the project begins and t_1 be the last period in the project cycle. The social planner is assumed to choose the level of inputs, s[t], for improving health at time t and the scale of the development project, z[t], to maximize welfare of a succession of identical and finitely lived representative villagers over time. s[t] is intended to represent investments such as development of health centers or provision of medicines to the population, while z[t] represents the microdam investment.

4.2.1 Forest and Health Stocks

The planner's choices affect the ambient health level of the population, forest stocks, and other agricultural yields. Formally, let a representative villager's health level H[t] be written,

$$H[t] = H(s[t], z[t], F[t], Y[t]) \qquad (4.1)$$

where F[t] is forest stocks and its effects on the availability and amount of fuelwood collected and used for heating and cooking at time t, which can have health implications. Firewood is a major source of energy and villagers spend an important share of their time collecting. Thus availability of forest trees as the result of planner's decision could affect the balance of time for other productive activities, leisure and health care. Y[t] is agricultural yields consumed at time t. Define K(.) as a disease function, arising due to project investments. This function represents some "stock' of disease, which could be measured as the number of individuals infected by some ailment within the target population, or as the frequency a representative individual is affected. For convenience we assume that the pre-investment level of disease is zero,[9] so that the increase in disease *incidence* as a project is implemented is given by the following state equation,

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[9] This closely follows the experiences of Tigray, where it is believed that microdams have substantially increased the incidence of water-borne diseases. For example, the prevalence of malaria historically has been found in less than 2% of the population during the dry months prior to dam use (Personal Communication with Tedros Gabre Kirstos, Tigray Health Bureau chief, January 1996).

$$\dot{H}[t] = -K(Y[t], FWC[t], s[t], z[t]) \qquad (4.2)$$

Where K(.) is a twice differentiable and convex 'disease incidence function' and is decreasing in its arguments, except for z[t](i.e., $K_z > 0$, $K_Y < 0$, $K_{FWC} < 0$, $K_s < 0$); FWC is the amount of fuel wood collected. The first partial derivatives show, reasonably, that the health is inversely related to the incidence of disease. Clearly, H[t] can be improved directly through investment in the health sector or indirectly through improved diet and living conditions, or increased fuel and food. Forest cover can impact health through fuel availability. Given a close relationship between forest cover and fuel collection, we assume that this impact is captured in the fuelwood collection variable, FWC[t] in (4.1)-(4.2). Finally, inputs in the health sector, through their effects on Y[t], FWC[t], and s[t] will improve health, but an increase in the water development project z[t] decreases H[t] due to its favorable impact on disease.

The forest stock available to the villager is a function of the development project level z[t], fuelwood collection activity FWC[t] and health level H[t]. Letting F(.) denote the forest stock, an expression for the rate of change in this stock over time is given by the equation of motion,

$$\dot{F}[t] = \mathrm{G}(H[t], \mathrm{FWC}[t], \mathrm{z}[t]) \qquad (4.3)$$

where G(.) is assumed to be a quasi-concave and twice continuously differentiable in its arguments with $G_H \leq 0$, $G_{FWC} < 0$, and $G_z \geq 0$. These conditions have intuitive meanings. Although the impact of health on F(.) is unknown we shall initially assume that increased villager health decreases the rate of increase in tree stocks by increasing time available for collection. The development project investment level should have positive impacts on the rate of forest stock growth.[10]

4.2.2 Agricultural and Fuelwood Production

Define Y[t] to be a concave agricultural production function whose arguments are the development project level (z[t]), the health level (H[t]), the amount of fuelwood collected FWC[t], and a vector of other agricultural inputs (X).

$$Y[t] = Y(FWC[t], H[t], F[t], z[t], X) \qquad (4.4)$$

Disease has an indirect impact on crop yield through its effect on health, which can have a detrimental impact on labor time availability. Sick household members work less, and household members who care for the sick have less time to work. The effect of FWC[t] on agricultural production is not known a priori. Increased access to forested land may free up land and labor for agriculture, and this may increase agricultural production. Ehui and Hertel (1989, 1990) argue that forest cover improves agricultural productivity through its protective services such erosion control and infiltration. However, in the long run, deforestation resulting from higher levels of FWC[t] could lead to reduced agricultural productivity as forest stocks, F[t], decline. For the purpose of our initial analysis, we assume FWC[t] and F[t] negatively and positively affect agricultural production, respectively. To simplify the dynamics, other agricultural inputs (*X*) will be considered optimally chosen in the theory, but we return to these later in the empirical section. Finally, we assume that the yield function is concave and twice continuously differentiable with ($Y_z > 0$, $Y_F > 0$, $Y_{FWC} < 0$, $Y_H > 0$).

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[10] Consider that in Tigray these investments typically include afforestation of the areas surrounding the dams.

Fuelwood collection is also an activity undertaken by the villagers. Let the amount of fuelwood collected be a function of health H[t], the project level z[t], and a set of resource and accessibility variables A:

$$FWC[t] = FWC(H[t], F[t], z[t], A). \qquad (4.5)$$

FWC[t] is assumed to be an increasing and concave function of H[t] and z[t]. z[t] directly increases FWC[t], given that the development projects we are interested in involve tree planting, thus improving accessibility to firewood. Higher H[t] increases FWC[t], since improved health affords households with more time for fuelwood collection. The variable 'A' in (4.5) represents all other variables, such as access, which impact fuelwood collection.

4.2.3 Social Planner's Problem

The previous equations describe how project levels, agricultural yield, forest stock, and inputs in health and agricultural sectors are related over the development project life span. Now we turn to determining the optimal scale of health and development project investments, as well as the optimal time path of forest stock and disease incidence (see, for example, Hueth and Regev 1974; Kamien and Schwartz 1981).

The social planner is assumed to make investment choices by maximizing a concave time separable net benefit function for the time during-the-project, i.e.,

$$B(Y[t], FWC[t]) = p_y Y(.) + p_f FWC(.) - C[t], \qquad (4.6)$$

at each time t, where

$$C[t]= C(z[t], s[t]) \quad (4.7)$$

is a convex cost function for the development project. The optimization problem can now be written as (4.8) below, with equations of motion defined in (4.2) and (4.3),

$$\underset{z[t],s[t]}{Max}\, \mathrm{W} = \begin{Bmatrix} \int_{t_0}^{t_1} \{p_y[t]Y(.) + p_f[t]FWC(.) - C(.)\}\exp(-\delta t)dt + \\ V(F[t_1], H[t_1]) \end{Bmatrix} \quad (4.8)$$

Subject to:

$$\dot{F}[t] = G(H[t], FWC[t], z[t]) \quad (4.9)$$

$$\dot{H}[t] = -K(FWC[t], Y[t], s[t], z[t]) \quad (4.10)$$

Where W is a measure of the present value of net benefits; δ is the social rate of time preference; p_y and p_f are per unit returns of agriculture and forestry at time t. The time horizon is defined through the life of the development project, $t_o \leq t \leq t_1$. Note that (4.8) also includes a salvage term, $V(H[t_1], F[t_1])$. This represents the expected net benefit of the development project that extends beyond the end of the time horizon; it depends on the terminal health level and the forest stock.

The above formulation is a standard continuous time optimal control problem with a salvage value (e.g., see Kamien and Schwartz 1986). The state variables are health and forest stocks, H[t] and F[t], while the control variables include inputs used in the health sector, s[t], and the development project level z[t]. The current value Hamiltonian associated with the problem described by equations (4.8) – (4.10) is given by,

$$\mathrm{H}^{c} = p_{y}Y(.) + p_{f}FWC(.) - C(.) - \lambda[t]K(.) + \mu[t]G(.) \qquad (4.11)$$

Where λ[t] and μ[t] are current value costate variables associated with health and forest stock, respectively. (In the subsequent analysis, the time subscripts will be suppressed for ease of simplicity, unless it is necessary to avoid ambiguity). The maximum principle requires that the following necessary conditions hold:

$$(a) \quad \frac{\partial H^{c}}{\partial \mathrm{z}} = p_{y}Y_{z} + p_{f}FWC_{z} - C_{z} - \lambda K_{z} + \mu G_{z} = 0 \qquad (4.12)$$

$$(\mathrm{b}) \quad \frac{\partial H^{c}}{\partial s} = -C_{s} - \lambda K_{s} = 0 \qquad (4.13)$$

$$(\mathrm{c}) \quad \frac{\partial H^{c}}{\partial H} = p_{y}Y_{H} + p_{f}FWC_{H} = \delta\lambda - \dot{\lambda} \qquad (4.14)$$

$$(\mathrm{d}) \quad \frac{\partial H^{c}}{\partial F} = p_{y}Y_{F} + p_{f}FWC_{F} = \delta\mu - \dot{\mu} \qquad (4.15)$$

$$(e) \quad \frac{\partial \mathrm{H}^{c}}{\partial \mathrm{FWC}} = p_{y}Y_{FWC} + p_{f} - \lambda K_{FWC} + \mu G_{FWC} = 0 \qquad (4.16)$$

$$(f) \quad \frac{\partial \mathrm{H}^{c}}{\partial \mathrm{H}[\mathrm{t}_{1}]} = \frac{\partial V}{\partial \mathrm{H}[\mathrm{t}_{1}]} - \lambda[t_{1}] = 0 \qquad (4.17)$$

$$(g) \quad \frac{\partial \mathrm{H}^{c}}{\partial F[\mathrm{t}_{1}]} = \frac{\partial V}{\partial F[\mathrm{t}_{1}]} - \mu[t_{1}] = 0 \qquad (4.18)$$

4.2.4 Optimal Level of Development Project

The necessary conditions can be used to describe in very general terms how a social planner determines the optimal level of the development project. Equation (4.12) indicates that, at an interior solution, the social planner undertakes investment in the development project so that the following holds,

$$\frac{\partial H^c}{\partial z} = 0 \Rightarrow (C_z + \lambda K_z) = (p_y Y_z + p_f FWC_z + \mu G_z) \qquad (4.12)$$

The RHS of equation (4.12’) comprises the marginal benefits of the project, which include the value of project-induced increases in villager income from agriculture, and increases in income from associated fuel collection activities. The left hand side represents the marginal cost of the project both in terms of operational costs (the first term on the LHS) and the marginal impact on health (i.e., the marginal increase in disease incidence) (second term on LHS).

Similarly, equation (4.13) indicates that investment in health inputs should behave according to,

$$\frac{\partial \mathrm{H}^{\mathrm{c}}}{\partial \mathrm{s}} = 0 \Rightarrow C_s = -\lambda K_s \qquad (4.13)$$

Where the first term on RHS is the marginal cost of health inputs, and the RHS represents the marginal benefits of health care inputs brought about by reducing disease incidence.

Equation (14) can also be rearranged to obtain,

$$p_y Y_H + p_f \mathrm{FWC_H} = (\delta\lambda - \dot{\lambda}) \qquad (4.14)$$

Here, the LHS represents marginal benefits from enhanced agricultural productivity due to increased health. The RHS represents marginal costs of improving health: these include the present value of resources diverted from other uses for health care (δλ) and the capital gain term (the time derivative of the future value of health capital) as well as increased deforestation. The latter cost component is based on the assumption discussed earlier that an increase in health exerts greater pressure on the open access resource.

Rewriting equation (4.15) we have:

$$p_y Y_F + p_f FWC_F = \delta\mu - \dot{\mu} \qquad (4.15)$$

Equation (4.15') shows an optimal rule for forest utilization: at the interior optimum, forest stock services should be employed to the point where the marginal benefit of forest capital equals the marginal cost. The RHS contains marginal benefits from enhanced agricultural production ($p_y Y_F$), due to improved soil and water conditions, and the marginal value of a unit of forest product ($p_f FWC_F$). The LHS contains the marginal costs of employing the services of the trees, i.e., the current benefits forgone from future use (δμ) minus the net capital gain of resource growth (this is the time derivative of the future value of forest stock).

The conditions above illustrate the link between health, forest stocks, and the project. We will now proceed by characterizing this interdependence, and then investigate the empirical magnitudes of the interdependence using our Tigray example and data.

4.2.5 Dynamics of the Development Project Level (z[t])

Assuming an interior solution for the optimization problem, we can solve for the optimal path of the development project over time. To do this we first solve for λ[t] using equation (4.12) and take its time derivative. Solving for time derivative of z[t], and using the maximum principle conditions (4.12-4.16) above, we obtain,

$$\dot{z} = \left[(p_y Y_z + p_f FWC_z - C_z + \mu G_z)\frac{K_{zz}}{K_z} - \{p_y Y_{zz} + p_f FWC_{zz} + \mu G_{zz}\} \right]^{-1} \times$$
$$\left[\begin{array}{l} \dot{\lambda} K_z - p_y (Y_{zH} \dot{H} + Y_{zF} \dot{F} + Y_{zFWC} \dot{FWC}) - p_f (FWC_{zH} \dot{H} + FWC_{zF} \overset{*}{F}) + \\ C_{zs} \dot{s} - \mu (G_{zH} \dot{H} + G_{zFWC} \dot{FWC}) - \dot{\mu} G_z \\ + \left(\dfrac{K_{zY} \dot{Y} + K_{zFWC} \dot{FWC} + K_{zs} \dot{s}}{K_z} \right) (p_y Y_z + p_f FWC_z - C_z + \mu G_z) \end{array} \right]$$

……..(4.19)

Now, using equations of motion, equations (4.12)- (4.16) and substituting for time derivatives of H[t], F[t], and costate variables λ and μ, yielding,

$$\dot{z} = \left[(p_y Y_z + p_f FWC_z - C_z + \mu G_z)\frac{K_{zz}}{K_z} + \{p_y Y_{zz} + p_f FWC_{zz} + \mu G_{zz}\} \right]^{-1} \times$$
$$\left[\begin{array}{l} K_z \left(- p_y Y_H - p_f FWC_H + \delta \dfrac{C_s}{K_s} \right) - p_y \left(Y_{zH} K + Y_{zF} G + Y_{zFWC} \dot{FWC} \right) - \\ p_f \left(FWC_{zH} K + FWC_{zF} \dot{F} \right) + C_{zs} \dot{s} - \left(p_y Y_{FWC} + p_f + \dfrac{K_{FWC} C_s}{K_s} \right) \left(G_{zH} K + G_{zFWC} \dot{FWC} \right) \\ - G_z \left(\delta \left\{ p_y Y_{FWC} + p_f + \dfrac{K_{FWC} C_s}{K_s} \right\} - p_y Y_F - p_f FWC_F \right) \\ + \left(\dfrac{K_{zY} \dot{Y} + K_{zFWC} \dot{FWC} + K_{zs} \dot{s}}{K_z} \right) \\ \left(p_y Y_z + p_f FWC_z - C_z + \left\{ p_y Y_{FWC} + p_f + \dfrac{K_{FWC} C_s}{K_s} \right\} G_z \right) \end{array} \right]$$

……(4.20)

The interpretation of ż[t] along its optimal path is as follows. When ż[t] is positive it is optimal to increase the project size over time, while a non-positive ż[t] argues for a shrinking development project investment over time.

The sign of ż[t] might vary through time. Equation (4.20) reveals that this sign depends on parameters regarding health, production, and forest stocks. For example, from the optimality conditions and our assumptions about Y[t], FWC[t], and K(.), the denominator in the above equation is negative, implying that the sign of the time derivative of z[t] is opposite the sign of the numerator, i.e.,

$$Sign\ \dot{z} \equiv$$

$$Sign \left[\frac{\begin{array}{l} K_z\left(p_y Y_H + p_f FWC_H - \delta \frac{C_s}{K_s}\right) + p_y\left(Y_{zH} K + Y_{zF} G + Y_{zFWC}\ F\dot{W}C\right) + \\ p_f\left(FWC_{zH} K + FWC_{zF} G\right) - C_{zs}\ \dot{s} + \left(p_y Y_{FWC} + p_f + \frac{K_{FWC} C_s}{K_s}\right)\left(G_{zH} K + G_{zFWC}\ F\dot{W}C\right) \\ + G_z\left(\delta\left\{p_y Y_{FWC} + p_f + \frac{K_{FWC} C_s}{K_s}\right\} + p_y Y_F + p_f FWC_F\right) \\ - \left(\frac{K_{zY}\ \dot{Y} + K_{zFWC}\ F\dot{W}C + K_{zs}\ \dot{s}}{K_z}\right) \end{array}}{\left(p_y Y_z + p_f FWC_z - C_z + \left\{p_y Y_{FWC} + p_f + \frac{K_{FWC} C_s}{K_s}\right\} G_z\right)} \right]$$

……(4.21)

Where K and G are rates of change in health level and forest cover over time. This expression can be simplified by defining the following parameters, each of which has an intuitive meaning:

$$\Psi = \left|\frac{K_z}{K_s}\right|; \quad \Omega = \frac{K_{FWC}}{K_s}; \quad \Phi = \left|\frac{K_{zY}\dot{Y} + K_{zFWC}\dot{FWC} + K_{zs}\dot{s}}{K_z}\right|;$$

$$\Theta = Y_{zH}K + Y_{zF}G + Y_{zFWC}\dot{FWC}; \qquad \Gamma = FWC_{zH}K + FWC_{zF}G;$$

$$\Sigma = G_{zH}K + G_{zFWC}\dot{FWC} \tag{4.22}$$

Ψ may be interpreted as the ratio of an increase in disease incidence due to the development project (i.e., decrease in the health level of the community) relative to health improvement that results due to investments in health (s[t]). A higher magnitude for Ψ indicates there will be more decline in health due to improved conditions for disease relative to improvement in health through increased inputs in the health sector. Thus, higher Ψ therefore provides rationale for decreases in project investments. The parameter Ω can be interpreted as a ratio of project benefits related to health relative to health improvements due to investment in inputs within the health sector (s[t]). A higher Ω provides rationale for increases in the project investment level. Φ measures the ratio of indirect marginal health benefits, from the development project, relative to the marginal impact of the project on disease incidence. The indirect health benefits follow from the positive effect of the project on agricultural yield, firewood collection, and project input interaction with health investment. A higher Φ provides rationale for increasing the size of the development project. Finally, the parameters Θ, Γ, and Σ measure primary benefits of the development project, i.e., increases in productivity (Θ), provision of the community with a source of energy for heating and cooking (Γ), and improvements in the natural resource base (Σ). These last three components represent what is typically evaluated for development projects if health impacts of the projects are ignored.

Using the above notation and assuming for simplicity that marginal costs of the project and health inputs (C_z, C_s) are constant, the optimal path of the development project investment z[t] can now be simplified to yield,

$$\text{sign}\,\dot{z} \equiv$$

$$\text{sign}\begin{bmatrix} -K_z\left(p_y Y_H + p_f FWC_H + \dfrac{\delta C_s}{K_z}\Psi\right) + p_y\Theta \\ + p_f\Gamma + \left(p_y Y_{FWC} + p_f + \Omega C_s\right)\Sigma \\ + G_z\left(p_y Y_F + p_f FWC_F\right) + \delta G_z\left\{p_y Y_{FWC} + p_f FWC_F + \Omega C_s\right\} \\ + (\Phi)\left(p_y Y_z + p_f FWC_z + \left\{p_y Y_{FWC} + p_f + \Omega C_s\right\}G_z\right) - \Phi C_z G_z \end{bmatrix} \tag{4.23}$$

Collecting terms, we arrive at a general rule for expanding and contracting development projects:

$$\dot{z} >,=,or < 0$$

$$\textit{if and only if}$$

$$\begin{bmatrix} p_y\Theta + p_f\Gamma + \left(p_y Y_{FWC} + p_f + \Omega C_s\right)\left(\Sigma + \delta G_z\right) \\ + (\Phi)\left(p_y Y_z + p_f FWC_z + \left\{p_y Y_{FWC} + \Omega C_s + p_y Y_F + p_f FWC_F\right\}G_z\right) \end{bmatrix} \tag{4.24}$$

$$>,=,or < \left[K_z\left(p_y Y_H + p_f FWC_H\right) + \delta\Psi C_s + \Phi C_z G_z\right]$$

The expression in the left bracket of equation (4.24) measures the marginal benefits directly or indirectly associated with the development project level. The terms in the right bracket measure the marginal costs of the project.

4.2.6 Policy Implications

The general rule in (4.24) requires the policy planner to go beyond the typical benefits and costs traditionally considered in project decisions. For example, in the case of microdams, project benefits that must be considered include (1) the direct economic benefit due to improved yield ($p_y\Theta$), (2) the direct financial benefits due to availability of firewood for heating and cooking ($p_f\Gamma$), and (3) the direct current and future economic benefits due to improved forest cover $\{(p_yY_{FWC} + p_f + \Omega C_s)(\Sigma+\delta G_z)\}$. Indirect benefits include impacts on agricultural yield, and forest stocks $\{(\Phi(p_yY_z + p_fFWC_z + (p_yY_{FWC} + p_f + \Omega C_s)G_z)\}$. The costs of the project consist of three types: (1) The direct negative impact of disease incidence on yield and forest cover $\{K_z(p_yY_H + p_fFWC_H)\}$, (2) the future cost of decreased health ($\delta\Psi C_s$), and finally (3) the financial cost involved with project implementation and management $\{C_z\Phi G_z\}$.

If project evaluation ignores the importance of health and resource/labor effects, only the first two and part of the third benefit terms would be considered, as would only the last cost component. How health is affected by the project, and how this spills over onto villager activities and the resource stock, will ultimately determine whether projects such as microdams are efficient. Other things being equal, lower values for Ψ, higher values for Ω and Φ may rationalize an increase in project inputs, z[t], based on equation (4.24). A higher positive magnitude for the commonly used project evaluation measures (i.e., Θ, Γ, and Σ) and lower cost component (4) do not necessary lead to overall economic feasibility of the project or justify an increase in its level. This is especially true for our case where there are health-related side effects of development projects.

4.3 Empirical Evidence

We now turn to our Tigray data to evaluate specifically whether microdam projects, widely implemented throughout the region, satisfy the notion of dynamic efficiency advanced above. The answer will depend on the links between irrigation, yields, fuelwood resources, and health of the population. Our data exist for one point in time. Thus, we will specifically evaluate condition (4.24) to determine whether the existing development investments should be expanded or contracted, after accounting for all indirect and direct benefits and costs.

Tigray is an arid to semi arid region, several hundred kilometers north of Addis Ababa, characterized by subsistence farm households raising predominantly cereal and vegetable crops for local consumption and sale (MUC, 1994). Recently the region has been the focus of intense civil unrest between Ethiopia and Eritrea, and this has increased pressure on natural resources as landless and homeless relocate throughout the region. Over a decade ago, the government of Ethiopia initiated a major rural development program (Sustainable Agricultural and Environmental Rehabilitation, or SAERT) to correct the decline in agricultural productivity and reverse environmental degradation. SAERT specifically focuses on water resource development through the construction of micro-dams and afforestation of the watersheds surrounding the dams. The increased water is expected to enable farm households in the region to switch from dry land to irrigated agriculture, and the afforested areas provide increased access to wood fuels. It is expected that this greater access will enable households to leave agricultural residues to decompose in their fields, increasing nutrient retention.

The World Health Organization has recently cautioned against expansion of these projects. Water borne diseases malaria and schistosomiasis are feared to have become permanent problem. A recent Mekele University and Tigray Health Bureau study has confirmed increased prevalence of these diseases, in addition to increased soil salinity brought about from introducing micro-dams in the arid and semi-arid climate (Mekele University College, 1994).

4.3.1 Data and Descriptive Statistics

The data were collected in collaboration with Mekele University College, Tigray, Ethiopia through a project funded by the World Health Organization (WHO). It contains a cross sectional survey of household heads over one major cropping season in 1996. The survey questionnaire contained a detailed list of questions on household production, consumption, natural resource use, sickness and costs associated with malaria and schistosomiasis. Enumerators trained by us administered the survey, and we monitored their progress throughout the survey period. Prior to full sampling, the survey was pre-tested during January of 1996. The full-blown survey sample distribution is based on proximity of villages (*Kushets*) to micro dams. For our study, eight microdam sites were selected: two from western Tigray, four from central Tigray, and two from southern Tigary. Thus the sample is representative of the entire Tigray regional state. From each microdam site, villages close to microdams and those far away were selected. The villages close to the dams are considered to be 'intervention' sites because of the impact of micro dams on household production, consumption and health; while villages far away are considered to be 'control' *kushets*. Mekele University College staff worked jointly with the Tigray Health Bureau and the WHO to ensure that the sample was stratified so that control villages minimized the impact of microdams on disease, while intervention villages maximized this impact. Out of 34 *kushets* selected, 19 were intervention sites and 14 were control *kushets*. Random samples of 20 to 25 household heads were selected from each of intervention and control village resulting in a total sample size of 730 households, after missing data were discarded.

Table 4.1 presents descriptive statistics for variables stratified by control and intervention villages. Medical health care expenses, number of days adult male and female are sick, and productive time spent caring for sick family members are higher in villages near microdams than in control villages. Forest stock, average cereal and vegetable yields, and average household income appear higher in the intervention kushets where microdams are within accessible distance. Table 4.1 shows that in Tigray there appears to be considerable productive time lost due to sickness. Irrigation use is also obviously higher in microdam villages, although only small fraction of households practice it (15.7%) compared to 4.9% in the control villages.

In our data we have two measures of disease, a personal assessment from each person as to the time lost from illness, and an assessment of whether they were suffering from malaria or shistosomiases. Given that people may not know what disease they have, the total time sick and not spent working, or the total time females spend in the home caring for the sick are more reliable variables for establishing a link between productivity and health. With this in mind, the prevalence of disease appears to indeed be higher in intervention villages. Malaria incidence, based on individual recall of condition, occurs with a prevalence of about 32% in microdam villages but only 19% in the control areas; while schistosomiasis incidence is reported to be higher for control villages.

4.3.2 Empirical Specification

Before estimating critical parameters contained in (4.24), several econometric issues associated with the data and theoretical model need to be addressed. In our data, we have two indicators of microdam project investment intensity. These are the distance of each village sampled from the nearest microdam, and the age of the microdam. Both measures are reliable indicators of disease incidence, agricultural yield, tree planting, and fuelwood collection, which are important in evaluating the project as we showed earlier. Households nearer to dams will obviously benefit more from increased access to water and fuel, but will also become more exposed to water-borne disease. Microdam age is also important, as older microdams consist of higher forest stocks and more developed water delivery systems.[11]

Health care inputs are measured in terms of household health-care related time inputs and variables describing financial costs incurred for medical treatment. Household health care time inputs include the amount of time spent taking care of sick household members as well as the amount of time lost due to sickness and not being able to work. Health care costs include money spent to visit health facilities as well as medicines purchased to treat sick family members.

Financial costs of project implementation are not available (i.e., we assume $C_z = 0$ in (4.24)). This is not unreasonable because households, and to some extent the government, does not bear any direct financial responsibility in dam construction or reforestation (this is covered by government agencies and NGOs). Therefore ignoring this does not preclude drawing the conclusions implied by the theoretical section.

[11] Other measures such as dam depth or size lacked variability among households and across villages in our sample.

Estimation of parameters defined in the theory section also requires obtaining time derivatives of variables. Since we do not have time series data, we can recover time derivatives by comparing the differences in variables between control (non-microdam) and intervention (microdam) villages. For instance, the rate of change in disease incidence equals the change in disease incidence (say, by number of days sick due to malaria) in control villages relative to the same variable in the intervention villages. Given that microdams age over time and our sample is random, if we were to sort the data by age of microdams, it would be similar to an unbalanced time series analysis.

The third econometric issue involves definition of household production and collection variables. Households produce different agricultural goods, which may be roughly categorized into two groups: cereals and vegetables. Thus, we must estimate two agricultural yield functions. Cereal production is measured as the amount of kilograms of cereal grains harvested per *timad* (land area unit) of cultivated cereal land converted to monetary unit using existing market prices for different grain types; the value of vegetable productions is similarly measured using observed prices for different vegetables. A fuelwood collection function must also be estimated, and our fuelwood variable is measured in donkey loads[12] of firewood collected during the survey season.

Functional specifications follow from our theory, i.e., equations (4.1), (4.4) and (4.5). We will assume that agricultural yields (cereal, vegetables), fuelwood collection, forest stock and disease incidence functions have Cobb-Douglas functional forms. Consistent with our theory, agricultural yield (Y_g), where g = crop type (cereal, vegetable), is assumed to be a function of deforestation (FWC), forest stock (F), household health and disease incidence (K), project inputs (z), household labor (L_g), household land and capital allocations to cereal and vegetable production ($LAND_g$, CAP_g), and other socioeconomic and demographic factors (D_y). Fuelwood is a major source of energy in the study area and households collect firewood for own consumption as well as for sale in the market; thus fuelwood collection is driven by market factors as well. The fuelwood collection equation is a function of household health (K), forest availability

[12] Donkey load is the main unit of firewood collected both for market sale and household own use. It is roughly equal to 25-30 kilograms.

(F), project inputs (z), market price for firewood and agricultural residues (P_F, P_A), household labor for fuelwood collection (L_C) and demographic and access factors (D_C). Forest stock is a function of fuelwood collection (FWC), health level (K), project inputs (z), and village and household level demographic and geographic factors (D_F). Forest stock is measured as the land area (in *timads*) covered by forest trees in the vicinity of a given village (usually considered as government forest) as well as tree plantation by individual farmers with the help of the project inputs (usually referred as household trees). Finally, disease incidence (K) is a function of fuelwood collection (FWC), health care inputs (s), project inputs (z), traditional village and household health care techniques (TT), and other demographic and geographic factors (D_K). K is measured as a total number of man/days sick (adult male, adult female, and children combined) due to malaria or schistosomiasis.

D_m, m = y, c, f, k comprise various socioeconomic, geographic and demographic factors important for agricultural production, fuelwood collection, forest stock, and disease incidence. Factors such as altitude, annual rainfall, household size, technology adoption, access to market and agricultural resources, health care center, firewood collection area, traditional health care techniques, house size and construction material[13], etc. can be important determinants of production, consumption, resource development and health.[14]

The assumption of Cobb-Douglas functions for equations (2), (3), (4), and (5) in the theory sections leads to a log-log linear simultaneous system of equations, where some of the dependent variables of one equation might be explanatory in another. We will therefore use a 2SLS procedure using LIMDEP (Greene 1997). Given there are no cross-equation restrictions, the order condition for identification is necessary and sufficient to uniquely determine the structural parameters (Hausman 1975; Chow 1968; Davidson and MacKinnon, 1993). Once the functions are estimated, the different

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13 Certain house types as well as sizes may be more suited to malaria transmission.

14 For example, a typical traditional health treatment technique is planting neem trees near household home. Neem trees act as a resistant habitat for malarial insects.

benefit and cost components shown on the theoretical section will be computed and compared to determine if the current level of the project inputs is optimal. All equations will be corrected for heteroskedasticity of unknown form.

4.4 Empirical Results

Tables 4.2 and 4.3 in appendix present 2SLS estimations for cereal and vegetable yield production functions, and for fuelwood collection and forest stock functions, respectively. Disease incidence function estimates are presented in Table 4.4.

Referring to the production functions, cereal yield has significantly benefited from microdam construction. Households located far from microdam sites have lower cereal production, and households near older more developed microdams have significantly increased cereal yield. Various labor inputs also play significant roles in cereal production: higher labor for cereal production leads to higher yield, as expected. However, cereal yield is negatively affected by sickness of males and children. Increases in forest cover improves yield, which is not surprising since the new tree plantations have multiple uses such as soil erosion protection.

The vegetable yield equation did not work as well as cereal production. However, vegetable production is also negatively affected by time spent caring for the sick and adult male time lost from production due to sickness, confirming our expectations that there are indeed costs to productivity and income due to microdams if health is reduced in intervention villages. Older microdams seem to reduce vegetable production, perhaps because cereal production increases for irrigated sites.

Fuelwood collection significantly depends on male, female, and child labor time, market factors and access to the microdam. Time spent sick and time spent caring for sick members by males and females both significantly reduce availability of firewood for either consumption or market sale. Clearly, reductions in health will in fact decrease the pressure on distant forest resources. Greater distance villagers must travel to the afforested microdam sites also reduces fuelwood collected. Adoption of improved stoves, a technical substitute for firewood, significantly reduces fuelwood collection, while use of animals (a proxy for capital) increases production.

An interesting contrast in the impacts of health on forest resources concerns the forest stock equation. These estimates show that time sick and time spent caring for sick seem to significantly improve tree cover, probably because of reduced collection pressures from reduced labor allocated to fuel collection. This is consistent with the negative effect labor has on the forest stock.

Finally consider the disease incidence function. This is the sum of the number of days adult male, adult female and children were sick in the household sampled during the cropping season. Disease incidence is negatively correlated with agricultural yield and fuelwood collection. The microdam distance variable carries a significant negative sign, showing that households far away from the dams are less likely to be sick or to lose productive time because of sickness. House construction material and house size also carry expected signs and are significant. A dummy variable measuring traditional malaria treatment techniques, i.e., planting of neem trees near the home has the expected negative effect on disease incidence even though it is not statistically significant.

4.4.1 Analysis of Benefits and Costs of the Development Projects

Recall our main goal was to evaluate, at one point in time, whether the current microdam investment level is efficient (see equation (4.24)). We can now use our estimates to construct the direct and indirect costs and benefits of these projects. Referring to equation (4.22) and (4.24), the important parameters to compute are Ψ, Ω, Φ, Θ, Γ, and Σ.

More formally, define $\beta_{i,j}$ as the coefficient on j^{th} explanatory variable on i^{th} equation of the simultaneous system, where i = Y, FWC, F, and K represent respectively the agricultural yield equation (Table 4.2), the fuelwood collection equation (Table 4.3), the forest stock equation (Table 4.3), and the disease incidence equation (Table 4.4).

From the definitions in (4.22), the following computations from our empirical estimates allow us to recover the important parameters,[15]

$$\Psi = \frac{(\beta_{K,z}/z)}{(\beta_{K,s}/s)}; \qquad \Omega = \frac{(\beta_{K,FWC}/FWC)}{(\beta_{K,s}/s)}$$

$$\Phi = \beta_{K,Y}\,\hat{Y} + \beta_{K,FWC}\,\widehat{FWC} + \beta_{K,s}\,\hat{s}$$

$$\Theta = \frac{\beta_{Y,z}Y}{z}\left(\beta_{Y,H}\,\hat{H} + \beta_{Y,F}\,\hat{F} + \beta_{Y,FWC}\,\widehat{FWC}\right) \qquad (4.25)$$

$$\Gamma = \frac{\beta_{FWC,z}FWC}{z}\left(\beta_{FWC,H}\,\hat{H} + \beta_{FWC,F}\,\hat{F}\right)$$

$$\Sigma = \frac{\beta_{F,z}F}{z}\left(\beta_{F,H}\,\hat{H} + \beta_{F,FWC}\,\widehat{FWC}\right)$$

Where the 'hat' notation indicates a time rate of change in the variable. As we discussed earlier, these time derivatives can be replaced by the difference in the variable between intervention and control villages (i.e., $\hat{H} \approx \Delta H / H$ for the health variable and so on)[16].

The expressions in (4.25), once computed, can be combined with market prices and partial derivatives computed from our Cobb-Douglas production functions to obtain equation (4.24). Since we will consider this equation at one point in time, the rate of time preference (δ) can be assumed constant and equal to the market rate for our data.[17] The partial derivatives can be obtained using the coefficient estimates and observed

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15 The derivations of these expressions are given in Appendix 4.A.

16 There were 8 microdams considered in this empirical exercise. The micro dams are built at different times, thus making our decision to replace the time derivatives by the difference in the variables between intervention and control village

17 We assumed δ, the rate of time preference, equal to current real interest rate in Ethiopia, which is about 10%.

values. Finally, the marginal cost of health care inputs will be recovered for time households spend caring for sick family members. Given there is no market for health care labor (i.e., households prefer to use their own labor for taking care of sick family members), a shadow price for family labor should be used as a proxy for health care labor wage following the literature (Jacoby, 1993; Thornton, 1994).

The results of these calculations are presented in Table 4.5. Ψ (the ratio of increase in disease incidence to health improvement) was estimated to be 0.749, indicating support for either implementing microdams or increasing the level of dams. Similarly, Φ (the ratio of indirect project benefits to its negative impact on health of a representative household) is 1.72, showing current project benefits far outweigh the negative health impacts, at least for our sample. Clearly, in our case the additional value of production and consumption afforded by the dams is greater than the marginal loss in income from increased disease or the resulting lost time.

Estimates of direct project impacts on yield (Θ), fuelwood collection (Γ), and forest stock (Σ) were estimated to be $\Theta = 1.109$, $\Gamma = 1.423$, and $\Sigma = 0.554$, respectively. These collectively imply that a unit increase in microdam project levels, measured by greater access will increase crop yields by 111%, firewood collection by about 142%, and forest cover by nearly 55%.

Finally, in Table 4.5 we present the marginal net benefit measure using individual components. This measure is the empirical realization of (4.24). The results imply that the current level of microdams in Tigray is not optimal, i.e., that increasing access to microdams through increased construction affords positive marginal net benefits. For example, referring to the table the marginal benefits (~53.80 Birr) are nearly three times the total marginal costs (~18.97 Birr)[18]. However, in making statements regarding the 'optimality' of increasing microdam investments, it is important to keep in mind that significant disease will accompany such a change. Our results show that the major cost to farmers from the projects is the reduced income resulting from time

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[18] Note that the total marginal cost does not include the direct financial costs of the project. This component of the costs is assumed to be covered by government or NGOs, which is typical of development projects in the study area.

lost from production while sick and time lost from production to care for others who are sick (~17.42 of 18.97 Birr over one cropping season). On the benefit side, firewood availability provides the highest marginal benefits, of 19.8 Birr over one cropping season.

4.5 Summary and Policy Implications

This paper has examined how public investments should be designed when their implementation affects natural resource allocation and use as well as health and disease in a developing country. This situation is commonly found, especially for countries considering water development for irrigated agriculture in regions with water-borne disease. An example is the Tigray region of northern Ethiopia, where microdams have been installed over the last decade by NGOs and government agencies. While these have brought increased yields and irrigation opportunities to villages nearest to the dams, there have also been productivity losses from increased incidence of disease. The productivity losses follow from increased sick time or time spent caring for the sick by working household members.

The theoretical model shows how productivity gains must be balanced with side effects projects have on disease in order to determine the optimal time path of investments in the projects. A decision rule is characterized which establishes the efficiency of increasing or decreasing investments. This rule highlights the balance between disease and water development from the perspective of a social planner. For example, the theoretical analyses show it is efficient to increase investments at the margin only if the marginal benefits in terms of yield and income are greater than the marginal costs of increased disease and reduced time spent working. Also included in the costs and benefits are the spillover effects of both the project and changes in disease on natural resource stocks. Such resource stock effects are critical to villager welfare, as reduced health may increase fuel collection pressures from local forests.

The paper uses an empirical study from Tigray to test the relationship between water development projects, health, and productivity. It first shows that microdams and time sick (and caring for the sick) are clearly related. Villagers living closer to the dams and those that irrigate using dam water are more likely to lose productive time due to disease, and are more likely to spend time at home caring for sick household members. The pressures on natural resource stocks and agricultural yields are also affected by the dams and by the resulting population health changes. Microdams increase yields for cereals and vegetables, and provide increased supplies of fuelwood. This decreases household dependence on residues for heating and increases market opportunities for household income generation. However, there is a relatively high cost of lost income due to decreased health for villages near the dams. Decreased health also increases collection pressures on local fuelwood stocks, increasing the likelihood of using agricultural residues as a source of heat. The presence of sickness is a major indicator of reduced crop and fuelwood yields and market income. These results clearly establish that the implementation of microdams cannot ignore the side effects these projects have on health.

Several policy implications follow from both the theoretical and empirical findings. In most cases where development projects are implemented, a failure to account for the side effects of the project on population health and local resource stocks will inevitably lead to inefficient levels of project investments. It is also likely that governments will make poor decisions regarding locations of development projects, and or even poor decisions regarding the use of the project at all. The empirical results also show that, at least based on current data, the marginal net benefits of Tigray's current microdam investments are positive. The lost income from increased time away from productive activities is compensated for by increased yields and market opportunities brought about through irrigated agriculture. However, it should be noted that this conclusion is based on efficiency and not equity. The analysis has not incorporated the disutility of sickness and pure health into the marginal net benefit calculation; caution should be made in interpreting the results. We are not saying productivity improvements due to microdams are worth human suffering in terms of disease, only that increased income at the margin from greater production opportunities is greater than the loss in income from reduced labor time from being sick or caring for the sick. Future work should seek to combine the disutility aspect of health with the productivity aspect to assess the overall benefits and costs of development projects. A starting point for this analysis might be recent work in contingent valuation that seeks to determine household willingness to pay to avoid poor health. Furthermore we do not know how much disease is due specifically to microdams –in future there needs to be better connection of economics and epidemiology if economists are to make statements about public investments in areas where health is affected. More attention needs to be paid to the complementarities between health, economic and environmental factors in order to realize the full social and economic benefits of development projects.

4.6 References

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Table 4.1 Variables used, their definitions and descriptive Statistics by control and intervention *kushets.*

Variable	Control		Intervention	
:	Mean	SD	Mean	SD
Micro dam age (in years)	--	--	5.075	3.219
No. of household members	5.255	2.231	5.093	2.248
Household total income[1]	1046.758	708.684	1080.720	854.916
Medical expenses for health care	13.679	46.686	23.097	55.233
Total cereal produce (Kilograms)	452.933	283.992	503.763	421.631
Total vegetable produce (Kilograms)	17.462	32.640	25.113	63.218
Total fuelwood collected	16.455	14.492	11.229	15.222
Total own landholding[2]	4.605	3.298	4.727	2.474
Total rental landholding	0.842	1.888	1.604	3.428
Forest stock level (in timads)	46.764	175.293	65.231	148.387
Animal unit[3]	3.698	2.762	3.644	3.632
No. of oxen owned	1.462	1.103	1.308	1.130
Irrigation dummy (0,1)	0.049	0.215	0.157	0.365
Own land for cereal	4.041	2.775	4.045	2.214
Own land for vegetable	0.334	0.706	0.318	0.895
Draught animal time-cereal production[4]	21.591	17.200	24.403	35.239
-fuelwood collection	8.101	18.117	6.144	12.985
-vegetable production	0.040	0.636	0.241	1.853
Fertilizer use in cereal production	30.834	38.543	27.693	38.753
Fertilizer use in vegetable production	0.000	0.000	0.130	2.051
Fertilizer price (Eth. Birr)	2.119	0.824	2.012	0.159
Hired labor used	4.401	15.271	12.991	44.051
Male labor wage rate	9.343	2.564	9.041	2.545
Female labor wage rate	6.735	1.648	6.632	2.207
Adult male labor-cereal production	38.150	33.076	38.280	45.032
-vegetable production	0.890	5.402	1.682	8.890
-fuelwood collection	11.829	24.518	6.157	12.599
Male off-farm wage labor	16.313	30.472	5.627	22.287
Male labor for taking care of sick	0.171	1.253	0.983	7.919
Male labor time spent sick	6.085	13.830	11.847	28.344
Adult female labor-cereal production	17.725	23.788	17.633	26.588
-vegetable production	0.385	2.750	0.398	3.777
-fuelwood collection	12.381	23.536	8.107	21.385
Female off-farm wage labor	7.271	15.194	1.549	11.006
Female labor time taking care of sick	0.704	4.601	1.158	7.288

Table 4.1 Variables used, their definitions and descriptive Statistics by control and intervention *Kushets* (cont…)

Variable	Control		Intervention	
	Mean	SD	Mean	SD
Female labor time spent sick	9.741	19.110	16.696	36.845
Child labor for cereal production	6.472	12.189	6.914	17.582
-fuelwood collection	0.207	1.664	0.224	2.257
-vegetable production	8.443	27.715	4.269	12.670
Child labor time spent sick	3.272	9.582	2.463	8.816
Malaria incidence dummy (0,1)	0.194	0.396	0.319	0.467
Schistosomiasis incidence (0,1)	0.085	0.279	0.048	0.213
Ownership of improved stove (0,1)	0.073	0.260	0.179	0.384
Ownership of neem tree (0,1)	0.057	0.232	0.200	0.400
Ownership of mosquito net (0,1)	0.000	0.000	0.019	0.208
Size of household home (1-large, 2-medium, 3-small)	1.930	0.760	1.876	0.763
Home construction material (1-stone/wood, 2-wood/clay, 3-clay/straw)	1.553	0.514	1.540	0.499
Distance to market/health center[5]	9.630	4.453	7.033	4.136
Distance to drinking water	1.243	1.468	1.375	1.303
Distance to agricultural land	2.247	2.660	2.117	2.962
Distance to micro dam	5.524	1.871	1.860	1.081
Distance to fuelwood collection area	10.188	8.829	7.741	8.977
Harvest time cereal price[6]	1.676	0.373	1.770	0.433
Harvest time vegetable price	2.160	0.466	2.228	0.536
Fuelwood price	13.328	4.091	14.202	5.891
Agricultural Residue price	14.997	5.724	15.172	5.417
No. of observations	247		483	

[1] measured in Ethiopian Birr (I USD ~8 Birr); [2]measured in timads (a traditional land measurement unit in Ethiopia. 1 timad ~ 0.5 hectare); [3]Animal unit is an index household livestock capital (oxe, horse, donkey, cow, mule, sheep, goat, etc.); [4] household or drought animal labor inputs are measured in man days/season for all activities (cereal and vegetable production, firewood and agricultural residue collection, off-farm wage labor, sick time, time spend caring for sick family members) (one man day is equivalent to 8 hours work per work day); [5]distances are measured in Kilometers; [6]Cereal and vegetable prices are in Birr per Kilogram, fuelwood price is in Birr per donkey load, agricultural residue price is in Birr per 30 kilogram sack, and wages are in Birr per man day.

Table 4.2 2SLS estimation of Cereal and Vegetable production Functions[19]

Variable	Cereal Production		Vegetable Production	
	Estimate	T-value	Estimate	T-value
Constant	-5.358	-2.882	1.272	2.420
Adult male labor in cereal production	0.093	2.817	--	--
Adult female labor in cereal production	0.013	0.478	--	--
Child labor in cereal production	0.054	1.971	--	--
Adult male labor in vegetable production	--	--	-0.759	-1.715
Adult female labor in vegetable production	--	--	3.107	2.300
Child labor in vegetable production	--	--	-0.680	-0.572
Adult male labor in health care for others	-0.755	-2.610	0.812	1.056
Adult female labor in health care for others	0.388	1.059	-1.009	-1.130
Adult male time sick	-0.089	-2.582	0.004	0.043
Adult female time sick	0.057	2.125	-0.100	-1.415
Children time sick	-0.157	-3.985	-0.201	-1.784
Household size	-0.209	-1.782	0.348	1.154
Area of forest cover	0.077	1.981	0.038	0.512
Hired labor used in cereal production	0.058	1.904	--	--
Irrigation dummy (1= yes, 0= no)	0.202	1.610	0.065	0.093
Agricultural capital utilized in cereal production	0.015	0.430	--	--
Animal unit	0.252	3.506	0.058	0.370
Agricultural capital utilized in vegetable production	--	--	2.369	1.397
Fertilizer used in cereal production	0.063	2.888	--	--
Fertilizer used in vegetable production	--	--	2.183	0.914
Total landholding	-0.079	-0.956	--	--
Total rented land	--	--	0.173	1.189
Seed inputs for cereal production	0.024	1.039	--	--
Micro dam age in years	0.208	2.346	-0.480	-2.296
Distance to health services	0.149	1.728	--	--
Distance to the nearest micro dam	-0.013	-0.165	-0.254	-1.472
Distance to agricultural land	-0.045	-0.720	--	--
Distance to drinking water source	0.091	1.033	--	--
Annual precipitation	1.273	4.548	--	--
No. of Observations	730		730	

The number in the first column of each regression is the estimated coefficient and the number in the second column is the estimated t-statistic.

[19] Dependent Variables are Log (Cereal production) and LOG (Vegetable Production); Except for binary ones, natural logarithm of independent variables is used in accordance with log-linear Cobb-Douglas specification.). Endogenous variables include adult male and female labor times for health-care-for-others

Table 4.3 2SLS estimation of Fuelwood Collection and Forest Stock Functions[20].

Variable	Fuelwood Collection		Forest Stock	
	Estimate	T-value	Estimate	T-value
Constant	8.415	0.828	-19.288	-2.589
Adult male labor in fuelwood collection	0.317	7.011	-0.179	-1.499
Adult female labor in fuelwood collection	0.109	2.795	-0.113	-1.161
Child labor in fuelwood collection	0.191	3.743	--	--
Adult male labor in agricultural residue collection	--	--	1.140	2.651
Adult female labor in agricultural residue collection	--	--	-1.057	-2.654
Adult male labor in health care for others	-0.320	-1.907	-0.474	-0.43
Adult female labor in health care for others	0.061	0.631	-1.859	-1.933
Adult male time sick	-0.274	-1.823	0.239	2.015
Adult female time sick	0.251	1.464	0.234	2.044
Children time sick	-0.732	-3.739	-0.175	-1.058
Household size	0.016	0.091	0.269	0.569
Area of forest cover	0.068	1.463	--	--
Hired labor used for fuelwood collection	1.116	1.784	--	--
Animal unit	0.217	2.192	-0.192	-0.675
Agricultural capital used in fuelwood collection	--	--	0.164	1.053
Total rented land holdings	-0.117	-1.283	0.101	0.299
Total landholding	0.130	0.972	--	--
Distance to own agricultural land	--	--	0.031	0.111
Distance to fuelwood collection area	--	--	0.499	1.919
Micro dam age in years	0.245	1.549	--	--
Use of improved stoves (Yes=1, No=0)	-0.287	-1.726	--	--
Distance to the nearest micro dam	-0.717	-5.737	0.263	0.876
Distance to drinking water source	-0.001	-0.009		
Annual precipitation	0.921	2.087	2.738	2.572
Altitude above sea level	-1.736	-1.431		
Size of household home (1-large, 2-medium, 3-small)	--	--	2.574	3.304
House construction material (1-stone/wood, 2-wood/clay, 3-clay/straw)	--	--	-2.175	-3.43
No. of Observations	730		730	

20 Dependent Variables are Log (fuelwood collection) and Log (forest stock); Except for binary ones, natural logarithm of independent variables is used in accordance to log-linear Cobb-Douglas specification. Endogenous variables include male and female health-care-for-others labor times. The number in the first column of each regression is the estimated coefficient and the number in the second column is the estimated t-statistic.

Table 4.4 2SLS estimation of Disease Incidence Function[21]

Variable	Total no. of days sick	
	Estimate	T-value
Constant	-7.678	-2.446
Household size	-0.124	-0.752
Adult male labor in health care for others	-0.830	-1.986
Adult female labor in health care for others	1.025	2.585
Amount of fuelwood collected (predicted)	-0.106	-2.259
Total cereal production (predicted)	0.031	0.391
Total vegetable production (predicted)	-0.048	-1.576
Financial expenses for health care	0.571	6.491
Size of household home (1-large, 2-medium, 3-small)	0.088	1.135
House construction material (1-stone/wood, 2-wood/clay, 3-clay/straw)	-0.182	-1.545
Use of improved stove	0.058	0.328
Ownership of neem trees	-0.120	-0.704
Ownership of mosquito nets	0.065	0.041
Household income	0.026	0.454
Distance to health service center	-0.038	-0.301
Distance to drinking water source	0.257	1.707
Distance to nearest micro dam	-0.351	-2.819
Distance to fuelwood collection areas	0.176	2.349
Micro dam age in years	0.122	0.927
Annual precipitation	1.427	3.165
Number of Observations	730	

[21] Dependent Variable is Log (sum of adult male and female, and children time sick); Except for binary ones, natural logarithm of independent variables is used in accordance with log-linear Cobb-Douglas specification. Endogenous variables include male and female health-care-for-others time).

Table 4.5 Estimates of model parameters, Total Marginal Benefits and Costs

Parameters/Benefits/Costs	Estimated Value
ψ	0.75
Ω	0.42
Φ	1.72
Θ	1.11
Γ	1.42
Σ	0.55
Total marginal benefits (in Birr)	53.82
Improved yield	1.93
Firewood Collection	19.80
Forest stock	14.79
Interaction	17.30
Total marginal costs (in Birr)	18.98
Cost agricultural land to trees	0.87
Sick labor and/or caring for sick	17.42
Financial cost of health care	0.69
Total net benefits (in Birr)	34.84

4.7 Derivation of Parameters

Define $\beta_{i,j}$ as the coefficient on j^{th} explanatory variable on i^{th} equation of the simultaneous system, where i = Y, FWC, F, and K functions. Note that coefficient $\beta_{i,j}$ is elasticity since we employed logarithm to linearize Cobb-Douglas functions. The parameters (Ψ, Ω, Φ, Θ, Γ, and Σ) can be computed as follows

1) $\Psi = \left|\frac{K_z}{K_s}\right|$

Where K(.) is a Cobb-Douglas form disease incidence function

Since, by chain rule, $\frac{\partial f}{\partial z} = \frac{\partial f}{\partial(\ln f)}\frac{\partial(\ln f)}{\partial(\ln z)}\frac{\partial(\ln z)}{\partial z} = f\frac{\partial(\ln f)}{\partial(\ln z)}(1/z)$, for any well defined function f(.), we have

$$\frac{\partial K}{\partial z} = K\beta_{K,z}(1/z), \frac{\partial K}{\partial s} = K\beta_{K,s}(1/s)$$

Which implies $\Psi = \left|\frac{K_z}{K_s}\right| = \frac{K\beta_{K,z}(1/z)}{K\beta_{K,s}(1/s)} = \frac{(\beta_{K,z}/z)}{(\beta_{K,s}/s)}$ (4.A1)

Similarly, it can be shown that $\Omega = \frac{(\beta_{K,FWC}/FWC)}{(\beta_{K,s}/s)}$ (4.A2)

2) $\Phi = \left| \dfrac{K_{zY} \dot{Y} + K_{zFWC} \, F\dot{WC} + K_{zs} \dot{s}}{K_z} \right|$

Derivation of estimable expression for Φ involves manipulation of cross-partial derivatives of estimated function:

$$K_{zY} = \frac{\partial}{\partial Y}(K_z) = \frac{\beta_{K,z}}{z}\frac{\partial K}{\partial Y} = \frac{K\beta_{K,z}\beta_{K,Y}}{zY} \qquad (4.A3)$$

Similarly $K_{zFWC} = \dfrac{K\beta_{K,z}\beta_{K,FWC}}{zFWC}$; $K_{zs} = \dfrac{K\beta_{K,z}\beta_{K,s}}{zs}$ (4.A4)

Using 4.A1, 4.A2, and the expression for $\dfrac{\partial K}{\partial z} = K\beta_{K,z}(1/z)$

$$\Phi = \frac{\dfrac{K\beta_{K,z}}{z}\left(\dfrac{\beta_{K,Y}}{Y}\dot{Y} + \dfrac{\beta_{K,FWC}}{FWC}F\dot{W}C + \dfrac{\beta_{k,s}}{s}\dot{s}\right)}{\dfrac{\partial K}{\partial Z}}$$,which simplifies to

$$\Phi = \beta_{K,Y}\hat{Y} + \beta_{K,FWC}F\hat{W}C + \beta_{K,s}\hat{s} \qquad (4.A5)$$

Where $\hat{H} = \dot{H}/H$

By employing quite similar manipulations, Θ, Γ, and Σ can be estimated by using the following expressions:

$$\Theta = \frac{\beta_{Y,z}Y}{z}\left(\beta_{Y,H}\hat{H} + \beta_{Y,F}\hat{F} + \beta_{Y,FWC}F\hat{W}C\right) \qquad (4.A6)$$

$$\Gamma = \frac{\beta_{F,z} F}{z}\left(\beta_{F,H}\ \hat{H} \right) \tag{4.A7}$$

$$\Sigma = \frac{\beta_{F,z} F}{z}\left(\beta_{F,H}\ \hat{H} + \beta_{F,FWC}\ F\hat{W}C \right) \tag{4.A8}$$

CHAPTER 5
CONCLUSIONS

5.1 Introduction

The sub-Saharan African (SSA) countries operate under resource-constrained environment and with formidable mandates of increasing economic growth, reducing poverty, and conserving their natural resource basis. Macroeconomic structural adjustment and public investment programs have been implemented to correct policy distortions and stimulate economic recovery. Factors such as weak micro-foundations and political infeasibility have contributed to policy reversals or failures of such programs in many SSA countries. Countries are still struggling with pervasive poverty, economic difficulties, food insecurity and environmental degradation. This dissertation is motivated in part by a notion that understanding how indigenous people respond to economic crises, rather than imposing top-down remedies, should be increasingly important for sustainable recovery.

This dissertation looked at two cases of economic recovery programs and the risks involved in two SSA countries, Zimbabwe and Ethiopia. Chapter 2 investigated how Zimbabwean households' consumption and savings behavior changed due to changes in economic circumstances in the early 90's—notably after the implementation of the structural adjustment program which was followed by successive droughts of the early 1990's. Chapter 3 investigated the interrelation between public water and tree development programs with health side effects and yield- and land-enhancing technology adoption decisions in northern Ethiopia. Finally Chapter 4 examined the optimality of development projects with health side effects in Ethiopia beginning with their theoretical implications and empirical realization of their impacts on health, production, and other resources.

This chapter presents conclusions and summarizes the major findings of the three distinct papers comprising the dissertation.

5.2 Summary and Conclusions to Chapter 2

This paper analyzed changes in consumption and savings behavior before and after drought and macroeconomic adjustments in Zimbabwe. It estimated the propensities to consume and save out of permanent and transitory incomes and tested the notions of permanent income hypothesis and precautionary saving motives under the SSA countries' context. In addition, it analyzed how changes in the overall economic situation translate into changes in propensities to save. The results show that in 1990/91 Zimbabwean households consumed the majority of their permanent income and saved the majority of their transitory income. The higher marginal propensity to save out of transitory income by households in this period implies that they used savings to smooth consumption. However, a polar version of the permanent income hypothesis could not be accepted. Following the drought and structural adjustment, however, households consumed the majority of both permanent and transitory incomes. Their savings behavior had been adversely affected by recurring drought and unfavorable economic change. Higher income variability is associated with reduced consumption indicating precautionary behavior on the part of households in the previous period.

The findings from this work have important policy implications. Zimbabwean households were forced away from risk management and precautionary saving behavior to that of heavy dependence on transitory income and remittances for consumption. The prolonged period of drought and macroeconomic change in the early and mid 1990s has limited households' long-term ability to manage risk. Furthermore, households may currently be facing credit problems due to declines in their incomes. The economy-wide decline in productivity may also constrain credit institutions. As a result, transitory income fluctuations may have serious welfare consequences.

5.3 Summary and Conclusions to Chapter 3

The adoption of more efficient farming practices and technologies that enhance agricultural productivity as well as improve environmental sustainability will be instrumental to achieving economic growth, food security and poverty alleviation. It is not surprising that there has been increased attention focused on achieving both technical change in agricultural production practices and improved natural resource management through diffusion of improved agricultural technologies, albeit with minimal success. The current study examined socioeconomic, environmental and cultural aspects of farmers that are important to adoption decisions. It modeled technology adoption as a sequential process where the timing of choices matters. The empirical tests, using data from the northern Ethiopian state of Tigray, showed strong evidence in support of sequential adoption.

The paper also identified several socioeconomic and agronomic factors important to farmer adoption decisions, the levels with which technology packages are adopted, and the tendencies to make sequential choices. The decision and intensity of technology adoption are highly correlated with the sequential nature of adoption, whereby farmers experiment with component technologies, acquire information through social learning, and engage in learning-by-doing before fully committing to the entire technology spectrum. Furthermore our work accounts for the importance of public investments and corresponding changes in health on adoption behavior. Steps taken to improve input and output markets and access to health care centers have positive impacts on adoption of yield- and land-enhancing technologies. Landholding (both own and rented), household head age and education level, access to market and health care centers, the age of and distance to micro-dams, and labor availability are found to significantly affect adoption probabilities, adoption levels, and the probability of sequencing choices. Investments in health are critical to adoption behavior even though the development literature has not paid enough attention to such interaction.

5.4 Summary and Conclusions to Chapter 4

This paper examined how public investments should be designed when their implementation affects natural resource allocation and use as well as health and disease in a developing country. This situation is commonly found, especially for countries considering water development for irrigated agriculture in regions with water-borne diseases. While construction of microdams and reforestation programs have brought increased yields and irrigation opportunities to villages nearest to the dams, there have been productivity losses from increased incidence of water-borne diseases.

The theoretical model developed showed how productivity gains must be balanced with side effects projects have on disease in order to determine the optimal time path of investments in the projects. A decision rule is characterized which establishes the efficiency of increasing or decreasing investments. This rule highlights the balance between disease and water development from the perspective of a social planner. Also included in the costs and benefits are spillover effects of the project and changes in disease on natural resource stocks.

The paper used an empirical study from Tigray, northern Ethiopia to test the relationship between water development projects, health, and productivity. It shows that microdams and time sick (and caring for the sick) are clearly related. Villagers living closer to the dams and those that irrigate using dam water are more likely to lose productive time due to disease, and are more likely to spend time at home caring for sick household members. The dams and resulting population health changes also affect pressures on natural resource stocks and agricultural yields. Microdams increase yields for cereals and vegetables, and provide increased supplies of fuelwood. However, a relatively high cost of lost income due to decreased health for villages near the dams decreases the desirability of the dams. The presence of sickness is a major indicator of reduced crop and fuelwood yields and market income. A failure to account for the side-effects of the project on population health and local resource stocks will inevitably lead to inefficient levels of project investments.