PINPOINTING PRODUCTION CONSTRAINTS FACED BY FEMALE-HEADED HOUSEHOLDS IN RURAL MALAWI

by

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(ABSTRACT)

In this study, an econometric model for testing whether female-headed households face unique constraints to maize production in Malawi is presented. A simulation is performed on the first-order equations of smallholder maize production functions and predicted marginal products are tested against observed input-output price ratios to detect input constraints and allocative inefficiency. Technical efficiency is also compared among headship gender categories. Results indicate that *de jure* female-headed households are less technically efficient than *de facto* female- and male-headed households. However, no evidence is found indicating that gender-specific input constraints exist. This study finds surplus labor present throughout Malawi's smallholder sector and discusses policy alternatives in the context of poverty alleviation.

DEDICATION

This thesis is dedicated to the professionals at the Virginia Tech Microcomputing and Technology Lab: Pam Crvich, Todd Pukanecz, and Jerry Spittle. Without their expertise, innovation, and unending patience, the analysis in this study would not have been possible.

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Chapter 1

The Plight of Female-Headed Households in Rural Malawi

1.1 Economic Conditions

Increasing agricultural productivity is vital to overall economic growth in developing nations. For Malawi, where agriculture contributes over one-third of the nation's GDP and provides over 90 percent of the population with their primary source of income, agricultural development is especially critical. In Malawi and many other African nations, colonial regimes left a legacy of "dualism within dualism," having established an agricultural estate sector producing crops for export supported by an impoverished sector of smallholder farms supplying food for domestic consumption. The Malawi government's emphasis on mobilizing cash crop estates to increase exports has reinforced this dichotomy in the three decades since independence, draining important resources and income-earning opportunities from the smallholder sector. Thus, increasing productivity in agriculture-- and smallholder agriculture in particular-- is crucial to attain both economic growth and equity in Malawi.

Although the smallholder sector accounts for over 80 percent of agricultural production, it is plagued by widespread poverty and growing land scarcity. Smallholders, by definition, are farmers cultivating land under customary tenure arrangements. The share of the national wealth held by smallholder farmers has decreased steadily since 1969 so that, despite the fact that they make up 72 percent of the Malawi's work force

(Sahn et al, 1990), they constitute 94 percent of the nation's poor (World Bank, 1995a). Further, per capita food production has declined by an average of five percent per year for the past fifteen years (World Bank, 1994). Severe foreign exchange shortages following recent devaluations and debt problems have precluded sufficient relief through imports. 55 percent of all children under five are stunted by malnutrition (Kennedy and Peters, 1992). Clearly, increasing productivity in the smallholder sector is imperative to achieve food security and economic growth in Malawi. However, any effort to augment production must recognize and address land, nutrition, and policy factors currently impeding production on small farms.

While hunger and poverty is widespread, the plight of smallholder households headed by females is particularly severe. Female-headed households constitute 34 percent of all smallholder households at any one time (Lele, 1991). Research shows, however, that a much higher percentage of households will experience a prolonged period of being headed by a female due to high rates of divorce, separation, and widowhood in Malawian society (Hansen, 1988). Female-headed households on average cultivate only 0.66 hectares-- 30 percent less than the average male household-- and have larger ratios of dependents to adult members. Female household heads also have much lower levels of education than men, and are less able to supplement household production with cash earnings or to secure credit. Further, local and hybrid maize yields in female-headed households are 10 to 30 percent lower on average than in male-headed holdings. Female

household heads are 36 percent less likely to adopt hybrid seeds, 33 percent less likely to use fertilizer, and half as likely to use pesticides as their male peers (NSSA, 1993).

All of these factors contribute to a much higher rate of poverty among female-headed smallholder households in rural Malawi. In the Southern region where land is most scarce, 60 percent of all female-headed households fall below the fortieth percentile of Malawi's national income distribution. Nationally, women smallholders are 30 percent more likely than male smallholders to be in the lowest 20 percent of the income distribution, and 26 percent more likely to be in the lowest 40 percent (World Bank, 1995b).

Numerous obstacles impede production and prosperity in rural female-headed households, including a lack of land, labor, cash, credit, and access to extension services. Land is growing scarce throughout Malawi (with over 80 people per square kilometer of dry land), but for women the problem presents additional complexities. In the matrilineal system of inheritance which predominates in southern and central Malawi, it is more difficult for women with small landholdings to find husbands. When they do marry, the males often must migrate in search of wage labor to supplement household income. This migration not only leads to the problems discussed below, but can leave a woman at risk of having land reappropriated if local authorities deem her incapable of cultivating the entire plot alone, or if they decide the household does not hold enough adults to feed to justify possession of the plot. Households with the smallest holdings thus are the most likely to be headed by females in matrilineal societies such as the Chewa and Yao.

In addition, women raised in matrilineal communities where land is scarce are sometimes compelled to leave their village to marry husbands living in less densely populated areas. Women in these cases often find themselves destitute in the event of divorce, separation, or widowhood, with no guarantee of continuing rights to cultivate their spouse's land. Women marrying within patrilineal social systems, such as the Moslem Tumbuka in the North, face similar uncertainties (Hirschmann, 1990; Mvula, 1986; Davison, 1993).

Female-headed households also experience a dynamic, two-pronged shortage of labor. First, they lack adult male labor. This shortage translates into a higher ratio of dependents to working adults within the household. It also reduces the ability of the household to supplement on-farm production with off-farm cash earnings. Women's wages in rural areas are between 30 and 75 percent less than wages received by men, whether women work as informal agricultural, commercial agricultural, or industrial laborers. Although opportunities for women to work in manufacturing have increased since 1980, wages have fallen as manufacturers have replaced males with female workers. Agricultural estates often prefer to hire males and will not hire women unless male laborers are unavailable. When they do hire women, estate managers often suppress their wages, insisting on paying them by tasks accomplished rather than time spent on jobs like weeding, sorting, and bundling (World Bank, 1991). Thus, women are less able than men to earn sufficient cash to supplement household production or purchase inputs such as fertilizer and hybrid seeds.

Second, female household heads can face overwhelming demands on their time outside of farm and wage labor. Women must spend enormous amounts of time in food preparation (Carr, 1991), childcare, and other household maintenance activities. One-third of Malawian households must travel between two and five kilometers to the nearest secure water source and to find firewood, taking valuable time from farming and other household responsibilities. Another fifth of all households are located over five kilometers from a clean water source (World Bank, 1991). In addition, women bear the "disease burden" of caring for sick household members[1], a burden which peaks simultaneously with the demand for agricultural labor during the wet season (Lele, 1991). The dynamic combination of these shortages of adult male labor and general household labor often prevents female-headed households from securing adequate food supplies to meet nutritional needs. The shortfall triggers a negative feedback cycle, where the malnutrition that results deteriorates household labor resources, further curtailing productivity and leading to even deeper poverty (World Bank, 1991).

In addition to land and labor shortages, female household heads experience problems gaining access to extension and credit resources. Only ten percent of extension workers in Malawi are female and most completed training in "female-oriented" home economics studies. Cultural factors limit extensive contact between the 90 percent of remaining male extension agents, and inhibit women's attendance at group meetings, which are the foundation of Malawi's block system of extension services (World Bank,

[1] The spread of AIDS is increasing the disease burden, as an estmated 2 million people in Malawi will be HIV positive by the year 2000 (World Bank, 1995b).

1991; Spring, 1988). This inhibition reduces women's access not only to extension support, but to credit because these farmer's groups are the government's primary mechanism for disbursing loans. Female-headed household are also at a disadvantage in competing for limited credit and extension resources because they generally are more resource poor. The land, labor, and cash constraints that these households face make them less attractive as potential borrowers and less compelling to extension agents who prefer to concentrate on better-off cash crop growers (Hirschmann, 1990).

In summary, widespread poverty within the smallholder sector and chronic food insecurity nationwide make increasing smallholder productivity imperative to alleviate hunger and facilitate economic growth in Malawi. As the majority of rural households will be headed by a female either permanently or temporarily, women must play a key role in this effort. Research suggests that female-headed smallholder households in Malawi face unique challenges that may impose gender-specific constraints to their production, adversely impacting yields and technology adoption. Therefore, an economic study of production in female-headed households is an important preliminary step in any policy program to alleviate poverty and encourage economic growth.

1.2 Problem Statement

All of these issues have led to debate concerning how to implement policy to improve productive capabilities on female-headed smallholder farms. However, there have been few studies at the household level determining exactly which of these factors

impede production, and how they interact to reduce smallholder crop yields. Because female-headed households constitute one-third of the smallholder population and have lower crop yields and technology adoption rates, it is impossible to construct effective agricultural policy without understanding the production constraints they face.

1.3 Objectives:

This study seeks to identify and quantify constraints to increased maize production in Malawi's smallholder sector. Specifically, its objectives are

1. To examine the productivity of different inputs into maize production to see if they vary according to the gender of the household head.
2. To pinpoint gender-differentiated occurrences of non-optimal input use.
3. To determine if incidences of non-optimal input use occur due to gender-specific input constraints.

1.4 Methodology

This study uses the first-order conditions of profit maximization to test whether female-headed smallholder households face a different set of constraints than male-headed households. It focuses on the production of maize, as maize is the primary subsistence crop for smallholder farmers. First, the parameters of the maize production function are estimated. The joint distribution of the parameter estimates then is used to create 100 draws of the first-order conditions for each factor input. For each category of headship gender, the actual data observations are incorporated into the draws to calculate a distribution for the model's predicted input-output price ratios.

Actual input-output price ratios are compared to these distributions to determine if the shadow price is significantly different than zero, implying the existence of a binding constraint to the use of the input. To assure that a nonzero shadow price indicates a resource constraint rather than gender-differentiated allocative inefficiency, the shadow prices are tested to determine if they vary with the changes in the stock of management-related variables. The parameters of dummy variables denoting headship gender are also tested to determine if female-headed smallholder households are as technically efficient as male-headed households.

The regression and testing will utilize data from the 1992-93 National Sample Survey of Agriculture (NSSA). The NSSA is a comprehensive survey of approximately 12,000 smallholder households throughout Malawi. It includes detailed information on variables including household structure, income, cultivation methods, and crop yields. Fertilizer prices and producer prices for maize are drawn from a World Bank AFTES Working Paper, "Malawi Economic Reform and Agricultural Strategy" and rainfall data are reported by the Malawi National Statistics Office.

1.5 Forward

To address the issue of lower yields and greater incidences of poverty among female-headed households, this study examines factor productivity among households of differing headship gender. It determines if there are instances of gender-differentiated non-optimal input use and determines if these instances are caused by gender-specific

factor input constraints. The following chapter provides more information concerning the macroeconomic environment and immediate human challenges facing female-headed households. Chapter 3 describes the methodology of this study, including the theoretical foundations, variable definitions, and econometric modeling. Chapter 4 explains the results of the study's actual statistical execution. Finally, Chapter 5 discusses the implications of the results, proposes appropriate policy alternatives, and elicits opportunities for further research into the dynamics of gender .

Chapter 2

An Overview of Conditions Facing Malawian Smallholders

2.1 Demographics

Malawi is a small country (188,000 km^2). Approximately one-third of its surface is covered by the blue waters of Lake Malawi. With a population of over 11 million, an average of 87 people occupy each square kilometer of dry land. This is four times the population density of Sub-Saharan Africa and twice the average density of the world as a whole. Although the United Nations Development Programme (UNDP) expects Malawi's population growth rate to average 2.6 percent for the rest of this century, it has averaged a phenomenal 3.4 percent over the past three decades, placing it among the fastest growing populations in the world. Malawi also has a total fertility rate of 7.6-- the highest in the world[2] (UNDP, 1994). As a result, the country not only faces acute and growing land pressures, but it also has a very young population: 49 percent of the population is under fifteen years old (UN, 1995). The dependency ratio-- the ratio of dependents to working adults-- within the average household is twice as high in rural as in urban areas (World Bank, 1995b), but rural female-headed households have the highest dependency ratio of all. A survey by Kennedy and Peters (1992) shows that female-headed smallholder households have a dependency ratio of 1.76, compared to

[2] The UNDP defines the total fertility rate as "the average number of children that would be born alive to a woman during her lifetime, if she were to bear children at each age according to age-specific fertility rates." (UNDP, 1994, p.220)

1.28 for male-headed households, leaving them with more mouths to feed and less adult labor to supplement family income.

2.2 Nutrition, Health, and Female Headship

Malawi suffers from seasonal and chronic food shortages. Malawi has experienced three droughts in the past five years. Being prone to drought, Malawi received 321,000 tons of cereal food aid in 1991/92 (World Bank, 1994), and 445,000 tons in 1994/95 (EIU, 1994III). The country attains only 87 percent of its daily calorie requirements on average (UNDP, 1994), and much of this never reaches the poorest Malawians. According to the Ministry of Health, "nutritional deficiency is....a principal or contributing cause for a dominant portion of preventable mortality in Malawi (Cromwell, 1992)."

Malnutrition has its biggest impacts on women and children. Nationwide, 76 percent of pregnant women receive prenatal care, 40 percent of births are attended by healthcare professionals, and 88 percent of one-year-olds are immunized. Although all of these indicators exceed the averages for other Sub-Saharan nations (UNDP, 1994), Malawi has by far the highest infant and under-five mortality rates in the region, and a maternal mortality rate of 620 per 100,000 births (World Bank, 1995b). The proportion of underweight children has increased 25 percent over the past two decades (UNDP, 1994). One out of every three children dies before the age of five (Cromwell, 1992).

2.3 Labor and Gender Dynamics

Kennedy and Peters (1992) report that most female-headed smallholder households in Malawi achieve between 50 and 52 percent of their caloric requirements, whereas male-headed households attain 57 percent. Because malnutrition can substantially decrease productivity (Behrman, 1993), inferior nutrition can exacerbate their lack of adult labor. Kennedy and Peters assert that to compensate for the absence of adult labor, female-headed households try to prevent malnutrition from weakening their children. They find that the poorest female household heads devote a higher proportion of limited household food supplies to their children. Children in *de jure* and the poorest *de facto* female-headed households[3] consequently have higher levels of nutrition manifested by higher weight-for-age and height-for-age measurements than their peers in male-headed and high-income de facto households (Kennedy and Peters, 1992). Other studies (Cromwell, 1992) also report that significantly fewer under-fives suffer stunting in female-headed households (Table 2.1).

Higher levels of nutrition among the children of female household heads could also reflect women's effort to conserve their own labor because labor in female-headed households is also limited by the "disease burden" that women bear in having to care for the sick (World Bank, 1991). A nationwide survey shows that women not only fall ill for an average of 19 days per year, but they also spend an average of 19.7 days caring for ill members of their household (Quisumbing, Schwartz, and Chibwana, 1992). Lele (1991)

[3] In a *de jure* female-headed household, a woman is the legal head of the household because she either has no husband or is separated. In a *de facto* household, the male spouse either is absent for periods of one month or longer in search of wage labor or is a polygamist.

Table 2.1
Child Nutrition and Headship Gender

Holding Size	% of Households with Stunted Under-fives	
(ha)	Male-Headed	Female-Headed
0.5	60	50
0.5-1	58	46
1-1.5	51	47

Source: Cromwell, 1992 (Table 4.9)

points out that this burden is highest during the rainy season, between November and April. Not only is the rainy season the time of peak demand for on- and off- farm labor, but it is also the "hungry period," when maize-deficit smallholders seek wage labor to buy food (Cromwell, 1992). Studies show that the majority of smallholder households exhaust their own food stocks by February, the middle of the rainy season (Sahn et al, 1990) and several months before the next harvest. Conflicting demands for women's labor thus create a labor bottleneck, forcing female heads to divide their time between tending their own plots, working for food, and caring for sick family members.

Researchers find that the conflicting time demands on female household heads for household maintenance and income earning are a major cause of food shortages (Lele, 1991; Due, 1991; Ferguson et al, 1990). Increasing fuelwood scarcity forces rural women to search longer and farther to secure wood, as it is the main source of energy for smallholder households (UN, 1995). One-third of rural women walk over an hour a day collecting firewood, and one-half walk nearly that far to fetch water (World Bank, 1991). A time-use study in rural Malawian villages finds that women work between 4 and 6 hours a day on domestic tasks in addition to farming activities (Engberg et al, 1991).

The government of Malawi asserts that the short, straight-edged hoes commonly used by smallholders add to these problems by making cultivation unnecessarily labor-intensive and propose developing and dispersing long-handled hoes with toothed blades (Carr, 1991). As female-headed households are less likely to own productive assets, they have few labor-saving options for farm work (World Bank, 1995b). The conflict between

crop cultivation and such domestic tasks as food processing and securing fuel and water can make female-headed households even more vulnerable to the cycle of undernutrition and depleted productivity. High numbers of closely spaced pregnancies also constrain women's labor by increasing threats of disease and malnutrition. Hirschmann (1990) posits that limited potential for further intensification of female labor in light of these compounded duties makes adoption of new technologies and income-earning activities impossible for female-headed households.

De jure female-headed households are less able to supplement their own food production with off-farm cash earnings than either male-headed or de facto female-headed families. *De facto* households, where the male spouse is away for periods longer than one month, often benefit from remittances from males who are engaged in wage labor elsewhere; they normally have higher off-farm income supplements than even male-headed households (NSSA, 1993). For *de jure* households, where the female head is unmarried, separated, or widowed, the main factor limiting off-farm income is a lack of available male labor. Estate farmers routinely discriminate against female laborers, hiring them only for the lowest-paying and most seasonal tasks unless men are unavailable (World Bank, 1991). As explained in Chapter 1, women receive lower wages across industries and even for informal (*ganyu*) agricultural labor. As a result, total off-farm income for *de jure* households averages only half that of *de facto* and male-headed household earnings (NSSA, 1993; Due, 1991).[4]

[4] See Appendix I for a gender breakdown of health and education statistics.

2.4 Agricultural Production Activities

For Malawians, "maize is life" (*chimanga ndi moyo*) (Smale et al, 1995). Maize is Malawi's staple food crop for both rich and poor. It constitutes an estimated 60 percent of the total land cultivated by smallholders with holdings larger than 3 ha and 75 percent of the area cultivated by the smallest farmers with holdings less than 0.5 ha (Cromwell, 1992). The extension manual of the Malawi Ministry of Agriculture (1994) recommends that "farmers should sell only surplus maize after insuring that they have stored enough for their family requirements until the next harvest (p.34)." Other major crops grown include groundnuts, pulses, sorghum, millet, and cassava.

Yields for both local and hybrid varieties are lower among the poor than the nonpoor, and are lowest for the poorest households in Malawi (Table 2.2). However, it is remarkable that yields for *de jure* female-headed households are the lowest within each income group. Yields for groundnuts and pulses notably do not follow the same gender-differentiated pattern within income groups. *De jure* female-headed households are much less likely than either *de facto* female-headed or male-headed households to adopt hybrid maize varieties. This low adoption rate is a key obstacle to food security, as hybrid maize provides about two and a half times more calories per hectare than local strains (Sahn et al, 1990).

Both male and female smallholders in Malawi lack access to credit and extension services. The rural credit system collapsed in 1994, when only 14 percent of smallholders repaid their loans to the Smallholder Agricultural Credit Administration.

Table 2.2
Breakdown of Yields by Income and Headship Gender

	Nonpoor (kg/ha)			Poor (kg/ha)			Poorest (kg/ha)		
Yields	**MHH**	***De facto* FHH**	***De jure* FHH**	**MHH**	***De facto* FHH**	***De jure* FHH**	**MHH**	**De facto FHH**	**De jure FHH**
Local Maize	1666 09	1741 82	1566 35	1401 4	1247 19	1306.42	1153.32	1262.66	1072.8
Hybrid Maize	2556 35	2657.23	2278 96	2026 81	2185 08	1845 33	1567 29	1716.95	1429 38
% adoption rate of hybrids	*43.4%*	*45.1%*	*31.4%*	*32 7%*	*34 3%*	*25.3%*	*32 3%*	*41.1%*	*18.7%*
Composite Maize	1782 79	1728.27	1776 77	1658 12	1435 93	1677.34	1631 51	1364 2	1566.25
Other Maize	1977 03	2513.4	1801 01	1453 02	1840	1371.27	1191.01	1496.58	1091 72
Groundnuts	774 86	837 52	785 49	577 76	506 48	620 16	487.63	282.9	495.04
Peas	497 37	365 5	556 9	489 54	392 34	450 95	426.34	397	456.64
Haricot Beans	326 69	448 81	337 11	324 37	160	375 44	363 33	404.05	288.81
Soybeans	854 81	830 34	705 93	767 03	602 73	713.06	620 75	728.77	601 32
Other Beans	481 75	456 31	502 57	418 7	395 72	410 01	359 82	374.54	365.38
Millet	749 58	740 6	743 26	640 61	788 82	585.24	529.36	840	534 31
Sunflower	615 33	929.94	625.8	576 31	797 29	520.94	412.54	646.67	616.27
Rice	2670 24	3208 72	2852.1	1370 51	960	2009 13	1279.59	1400	871 11
Sorghum	4892 22	N/A	756 24	N/A	N/A	562.48	840.84	N/A	N/A

Source: NSSA 1993

Political parties led farmers to believe that the loans were a gift from the government in the months preceding Malawi's first democratic presidential elections, which took place in August 1994. The misinformation, combined with confusion over the concurrent distribution of drought relief, caused widespread default, so that few smallholders were eligible for credit for the 1994-95 growing season. The acute lack of credit prompted a 61 percent reduction in hybrid maize seed purchases and a 57 percent drop in fertilizer purchases in the smallholder sector (EIU 1994II). Similar confusion over drought-relief disbursement also left farmers expecting grants of seeds and fertilizer for the 1995-96 growing season, contributing to another drop in fertilizer sales of over 50 percent from pre-1994 levels (EIU 1996). The Malawi government, in collaboration with the World Bank, has established the Malawi Rural Finance Company to avoid such misunderstandings in the future by giving the rural credit system a more commercial orientation (EIU 1994IV). In 1993, before the rural financial crisis, approximately 15 percent of smallholder farmers utilized credit (NSSA 1993). This number is high when compared to other African nations (Sofranko and Fliegel 1989). However, it has negative implications for technological development among the remaining 85 percent of smallholder producers because smallholders purchase 75 percent of their total hybrid maize seeds and fertilizer with credit (EIU 1994II). Until the credit collapse, government spread access to credit by integrating seasonal loans into agricultural extension club functions. The clubs grew rapidly throughout the nation, but incorporated only about one-quarter of farm households (Gladwin 1992). Further, because credit to the entire

club was suspended if one member defaulted, these clubs were likely to screen out labor-poor farmers with small holdings as poor credit risks. Despite the success the club strategy brought in spreading credit and extension services more widely, it skewed access toward larger, more commercially oriented holdings (Sofranko and Fliegel 1989).

Because they are more likely to be resource poor, female-headed households have always been less likely to have access to these services. The World Bank (1991) reports that only 1 percent of all medium-term agricultural borrowers in the early 1980s were women. The situation improved somewhat during the late 1980s with the proliferation of Women's Groups. Whereas smallholders with less than 1 ha account for half of the membership in Women's Groups, only one-third of members in traditional extension clubs had such small holdings. Female household heads make up 40 percent of Women's Groups members, and almost 80 percent of these female heads cultivate less than 1 ha. Like traditional farmers' clubs, the Ministry of Agriculture (MOA) organized Women's Groups to provide contact with field-level extension agents and to disburse credit (Sigman et al, 1994). The MOA also began to disburse fertilizer and seed packets purchased with credit in smaller sizes, which would be more suitable to smallholders farming holdings of less than one hectare (Lele, 1992). Nevertheless, in the 1992-93 agricultural growing season, only 4.5 percent of *de jure* female household heads used credit to buy fertilizer, compared with 18 percent of male farmers (NSSA, 1993).

2.5 The Policy Environment

2.5.1 Historical Context of Bias toward Estate Agriculture

Malawian policies favoring estate production after independence have had adverse consequences for smallholder farmers. A conflict of interest between the smallholder and estate sectors first emerged in Malawian agriculture with the establishment of the British Protectorate in 1891. British farmers arriving in Malawi to start coffee, tea, cotton, and tobacco plantation estates faced shortages of farm hands. Initially, the colonial regime supported the development of the estates through land transfers and by imposing taxes on native Malawians to force them to supply inexpensive wage labor. It also enforced the *thangata* tenant system until 1915, which forced peasants to supply labor to the estates in exchange for use of a plot of land (Christiansen and Kydd, 1982). However, prohibiting smallholders from growing lucrative cash crops was the principle way the colonial regime prevented native farms from competing with settlers for scarce hired labor (Palmer, 1985).

Despite assistance from the colonial government and Imperial trade preferences accorded by Britain, estate agriculture in Malawi was moribund. The failure of estate owners to rotate their crops, high rents on Crown Lands, and exorbitant railway cargo rates to ports in Mozambique depressed profits and drove many settler farmers bankrupt. The collapse of coffee prices at the turn of the century and of tobacco and tea prices in the early 1930s wielded fatal blows to estate production. By 1935, British estates produced only 3 percent of cotton grown in Malawi. The number of tobacco farmers dropped from

229 in 1928 to 82 in 1935. The setbacks compelled most of the few remaining estate owners to turn their land over to sharecropping. They allocated export crop production to native Malawian farmers who could more efficiently rotate cash crops with food crops, and who could be evicted if they did not sell the crops to their landlord at a favorable price (Palmer, 1985). The failure of the British estates resulted in the dominance of small-scale agriculture from the late 1920s through the mid-1960s (Christiansen and Kydd, 1982).

2.5.2 Post-Independence Agricultural Policy

In the years following Malawi's independence from Great Britain in 1964, government shifted its focus back to estates, seeking to encourage foreign-exchange earning export crop cultivation. Tobacco, tea, sugar, coffee, cotton, and other agricultural products now constitute 88 percent of Malawi's total exports (World Bank, 1990). The government passed the 1965 Land Act, stipulating that estates operate on freehold or leasehold land and smallholders on customary land. The Act specifically allows the reappropriation of customary land to freehold and leasehold tenure for estate use (Cromwell, 1992). From 1968 to 1981, the amount of arable land cultivated by estates grew from 14 percent to 19 percent. The conversion continued through the 1980s until 14.5 percent of customary land in Malawi had been diverted to the estate sector. To address poverty in the smallholder sector, from 1968 until 1978 the new government espoused a "major projects" approach. However, the high-intensity projects both lacked

effectiveness within their localities and were impossible to replicate on a larger, national scale due to resource constraints (Khaila, 1995).

The state also established a crop marketing board, the Agricultural Development and Marketing Corporation (ADMARC). The board had the sole authority to determine producer and consumer prices for food commodities and maintained a fixed, pan-territorial price for maize each year. Government required smallholder farmers to sell their crops through ADMARC, which effectively diverted profits from the smallholder sector to subsidize domestic food prices, as well as estate cash-crop production. By the late 1970s, ADMARC had invested 66 percent of its profits from the sale of smallholder food crops directly into estate production. It also used its investment portfolio to gain control of Malawi's two commercial banks. By 1980, over 50 percent of all commercial bank advances went to commercial agricultural ventures with little adherence to standard risk-management policies (Christiansen and Kydd, 1982) and at subsidized interest rates.

Under 1968 Special Crops legislation, smallholders were prohibited from growing the most lucrative cash crops, sheltering estates from small-scale competitors. It delegated flue-cured and burley tobacco for export to estates, leaving oriental fire-cured tobacco, as well as cotton, for smallholder cultivation. Other government policies suppressed minimum wages in the estate sector to keep export crops competitive on world markets and prohibited smallholders from receiving the same export parity prices for their crops that estates were paid (Cromwell, 1992).

The effects of these policies are clear. The combination of taxing output and reinstituting colonial restrictions against smallholder production of export crops reduced the returns to labor in the smallholder sector. The siphoning of wealth from smallholders is evident by the growth of the number of wage laborers in Malawian estate agriculture at a rate of 10 percent per year between 1968 and 1980-- far outpacing population growth. This funneling of labor occurred despite 6 percent annual decreases in the real wage rate during this period, evidence that ADMARC policies depressed the profitability of production on smallholder farms (Christiansen and Kydd, 1982). Between the years 1968-69 and 1984-85, the share of the national wealth in the hands of Malawian citizens in the lower 80 percent of the income distribution dropped from 44 percent to 34.3 percent. The share of wealth held by citizens in the lower 40 percent of the income distribution fell to almost half of its 1968-69 level, from 18.8 percent to 9.5 percent (Pryor, 1990). Sahn, Van Frausam, and Shively (1994) estimate that income accruing to farmers with holdings less than 1.5 ha would have been 13.7 percent higher had they been offered the same prices for cash crops that estate producers received. Both *de facto* and *de jure* female-headed households suffered disproportionately, as they are 19 and 49 percent (respectively) more likely than their male-headed counterparts to be in the poorest 20 percent of the population (NSSA, 1993).

Because of government policy bias in favor of estate agriculture, estates grew both in number and in proportion of total arable land. Due to the conversion of traditional land to estate land, coupled with high population growth rates, the average

holding size of smallholder farmers fell from 1.54 ha to 1.16 ha between 1968-69 and 1980-81. During the same period, the number of households with less than 2 hectares of land increased from 28 percent to 81 percent (Sahn et al, 1990). Growing land pressures impose hardships on smallholders since 1.25 ha is the estimated minimum holding required to meet subsistence needs (Sofranko and Fliegel, 1989). To address this shortage, household members often seek wage and other off-farm employment. One survey of burley tobacco estates in the Kasungu region found that 90 percent of tenants farmed on estates as a means of earning income to supplement production on their own meager holdings (Sahn et al., 1990).

The distribution of land in Malawi has severe implications for the productivity of the land and for food security. First, it reduces the aggregate intensity of land use in Malawi because large portions of land allocated to the estate sector lie fallow each year (Pryor, 1990). Estate owners leave between 72 and 94 percent of their land uncultivated each year (Cromwell, 1992), far more than is necessary for rotational purposes. As rents on leasehold land are low and rent collection is often not enforced and they have had no incentive to cultivate more intensively (World Bank, 1987). Second, smallholders seeking wage labor to supplement household income do so at the expense of the productivity of their own land, as they are forced to neglect seeding and weeding tasks on their own plots during times of peak off-farm labor demand (Christiansen and Kydd, 1982). Food shortages stemming from land constraints are evident as 83 percent of households with less than 0.7 ha and 72 percent of households with between 0.7 and 1.5

ha exhaust their food stocks by the pre-harvest month of February (Sahn et al., 1990). The 72 percent of smallholders owning less than one hectare (World Bank, 1995) simply can not produce adequate calories from their landholdings using traditional technologies.

2.5.3 Reform Initiatives

The Malawi government began to reform policies adversely effecting the rural population with the help of a series of Structural Adjustment Loans (SALs) occurring in 1981, 1984, and 1985. The government initiated the privatization of ADMARC marketing posts in 1987. ADMARC and private traders now compete in the more well developed market locations. However, farmers in remote areas have suffered as a result of this liberalization. They are now subject to high transactions costs passed down by the new private traders (Cromwell, 1992). Licensing requirements, capital shortages, and a highly regulated transport system which, among other things, prohibits carrying passengers and goods in the same vehicle, have prevented traders from penetrating the most remote rural outposts (Smith, 1995).

Consequently, merchants have not filled all of the 20 percent of ADMARC posts that were completely shut down and farmers there may have no market access at all (Christiansen and Stackhouse, 1989). Remaining ADMARC posts do not open until July 1, forcing small-scale farmers who need to sell their harvest early to accept lower prices from traders at the beginning of the marketing season (Cromwell, 1992). ADMARC has forgone its pan-territorial pricing policy and now maintains maize prices nationwide

within a broader, government-specified band (EIU, 1995III). However, even with pan-territorial price ceilings in effect, maize-deficit households in remote areas paid maize prices as much as three times higher than the official ADMARC ceiling during the hungry season between December and March (Cromwell, 1992). Higher prices arising since liberalization are a positive development for maize-sufficient or cash-cropping households with market access. Nevertheless, higher prices and shutdown of the smallest ADMARC marketing posts hurts both maize-deficit households and households in remote areas who either must bear higher transport costs with private traders, or who may have no market access at all.

The government instituted the Fertilizer Subsidy Removal Program in 1983 under SAL II largely because the smallholder fertilizer subsidy was a major cause of ADMARC's financial difficulties (Christiansen and Stackhouse, 1989). As much as 35 to 40 percent of the subsidized fertilizer leaked to the estate sector (Mtawali, 1994) and there were questions as to the overall level of production efficiency encouraged by the program. Despite the removal of all elements of the subsidy other than increases in transportation costs[5] (Mtawali, 1994), fertilizer use by smallholders increased over 70 percent between 1983 and 1990 (Sahn et al., 1990). Nominal fertilizer prices have tripled in the past year due to further subsidy removals and the depreciation of the Malawi Kwacha. Steep price increases, combined with recent credit confusion, caused the sharp drop in this year's fertilizer purchases (EIU, 1996I). Although fertilizer has become more

[5] The Malawi government continued to subsidize the cost of transporting fertilizer into the country in an attempt to offset large increases in transport costs caused by the war in neighboring Mozambique.

expensive, liberalization of fertilizer imports has introduced competition from private traders and chemical companies, making nutrient inputs more widely available throughout the agricultural sector (EIU, 1996I).

Crop regulation and output price reform have mixed effects on welfare in the smallholder sector. Under the 1990 World Bank Agriculture Sectoral Adjustment Credit program, the government began to allow smallholders to grow burley tobacco under a restrictive quota system (Mtawali, 1994). Smallholders now account for almost 40 percent of Malawi's burley tobacco production. However, efforts to ensure price stability by imposing ceilings on consumer prices have conflicted with output price reform. Even amidst large producer price increases under recent liberalization efforts, land pressures prevent price-responsive smallholders from expanding their holdings to exploit profits from lucrative crops, so that they must reallocate limited subsistence cropland (Cromwell, 1992). Smallholder confidence in the year-round availability of food in the marketplace must increase before widespread diversification can take place.

2.5.4 A New Commitment to Alleviating Poverty

In addition to continuing economic reform, the nation's first democratically elected president, Bakili Muluzi, has declared a commitment to poverty alleviation since his inauguration in 1994 (EIU, 1994III). His administration lost no time in eliminating primary school fees. Funding for public education has tripled, with a special emphasis on primary schooling, which has grown from 45 to 71 percent of total public education

spending. Although they remain low, primary school enrollments have increased 60 percent nationwide since 1993. The majority of the increase in primary-level funding was devoted to teacher salaries, but there is still a severe shortage of trained instructors, classrooms, and materials (World Bank, 1995).

Despite four civil service strikes since the beginning of his term, Muluzi's administration is launching a multitude of other programs to improve the welfare of smallholder farmers. In September 1995, he initiated the Malawi Social Action Fund (MASAF) with support from the World Bank. MASAF is designed to allocate funds to localities for their own community development, with project design and additional cash or in-kind investments emerging from a hierarchy of grassroots committees nationwide. With the help of the World Bank and the Nordic Development Fund, the government has initiated an extensive four-year project building water reservoirs to make the country less prone to drought. (EIU, 1995IV) The administration is also considering the politically divisive issue of land reform (EIU, 1995II).

2.6 Examining The Economic Position of Female-Headed Households

Thus, a survey of literature on economic conditions in Malawi indicates that female-headed households may face unique obstacles in agricultural production. Possible constraints include a shortage of adult labor and smaller landholdings. Having fewer opportunities to earn cash income and less access to credit and extension than males may also prevent female household heads from adopting fertilizer and improved maize

varieties. Policy bias toward estate agriculture in the three decades following independence contributed to increased poverty and land pressures throughout the smallholder sector, but female-headed households now constitute a disproportionately high fraction of Malawi's poor. The current president of Malawi has established poverty alleviation as a new commitment for government policy, but policy efforts can not be effective without taking into account the production constraints of the nation's poorest households. The following chapter outlines the methods of this study, which tests for gender-specific constraints that may impede efforts to increase productivity for female-headed households.

Chapter 3

Methodology

3.1 The Analytical Context

The purpose of this study is to examine constraints to agricultural production in Malawi with special emphasis on the gender of the household head. The review of previous studies, government policies, and empirical evidence in Chapter 2 indicates that female-headed households probably face production constraints that male-headed households do not. As the majority of smallholder households are either permanently or temporarily headed by a female, such impediments, if they exist, present a major obstacle to increasing agricultural productivity. Therefore, uncovering gender-specific production constraints is an essential step to alleviate poverty.

The study examines divergences from profit-maximization by headship gender to explore the implications of gender. Profit maximization criteria more typically are used in studies examining efficiency on smallholder farms. Two such studies using data from West Bengal and the Punjab use this approach to illuminate production complexities on small farms in India, but both ignore the possibility that various farms might be operating under entirely different production constraints. (Kumbhakar, 1994; Sidhu and Baanante, 1981) A study focusing on technology adoption in Ethiopia addresses this possibility, but assumes that variation would occur among regions, rather than among households of differing socioeconomic or demographic make-up. (Kidane and Abler, 1994) Although

many studies, like these three, ignore the possible impacts of gender in smallholder production. Sahn, Van Frausam, and Shively(1994) typify the way economic analysts approach headship gender. They construct a model of the entire Malawian smallholder sector to assess the impact of removing current restrictions on tobacco cultivation. However, they distinguish between male- and female-headed households only to discuss the determinants of child nutrition, not to examine production constraints or resource distribution. (Sahn et al. 1994)

Several researchers have more intensively explored the dynamics of female headship using econometric analysis without examining household production. Kennedy and Peters (1992) use regression analysis to examine the roles of headship and income in determining child nutrition. They discover that *de jure* and the poorest *de facto* female-headed households devote more calories to their children to overcome severe cash and labor constraints, but they do not explicitly prove that such constraints are unique to female-headed households. Gladwin (1992) also examines headship gender in an econometric study of factors affecting fertilizer use. She finds that, controlling for income and credit access, female-headed households are no less likely than male households to apply fertilizer. Although she explores credit constraints facing women through a qualitative decision-tree model, she does not use her econometric model to explore possible links between gender and other constraints on agricultural production. Thus, there have been no studies that explicitly examine the impact of gender-specific

constraints to smallholder production that use econometric analysis based on the economic theory of production.

3.2 Theoretical Foundations

The primal approach to profit maximization is employed in this study. Assume that agricultural production can be modeled as the function

(1) $y = f(v, z, g, m, e)$,

where

y = agricultural output

v = a vector of m variable factor inputs

z = a vector of n inputs that are possibly quasi-fixed

g = a vector of headship gender variables

m = a vector of management variables affecting efficiency in input use

e = an environmental variable

In this model, quasi-fixed inputs are factors that could possibly be constrained, that is, factors that may be limited by supply or cash shortages or that may not be available in sufficiently divisible quantities. It is unknown which of these inputs is constrained; they are treated as variable until each one is tested for a constraint. Equation (1) is the unrestricted model of agricultural production.

Assuming that smallholders maximize profits, the household production decision can be represented as the following Lagrangian function for profit maximization:

$$Max\ L = p_y f(v,z,g,m,e) - \sum_{i=1}^{m} w_i v_i - \sum_{i=1}^{n} r_i z_i + \sum_{i=1}^{n} \lambda_i (\bar{z}_i - z_i),$$

where p, w, and r are the output, variable input, and quasi-fixed input prices, respectively. The value of the constraint for quasi-fixed factors of production is $\bar{z}_i$ and the shadow price[6] for each quasi-fixed input is λ_i. The Kuhn-Tucker conditions necessary for a solution to the optimization problem are

(2) $$\frac{\partial L}{\partial v_i} = p\frac{\partial f(v,z,g,m,e)}{\partial v_i} = w_i \qquad for\ i = 1,\ldots,m$$

(3) $$\frac{\partial L}{\partial z_i} = p\frac{\partial f(v,z,g,m,e)}{\partial z_i} - r_i - \lambda_i \leq 0\ ;\quad \lambda_i \frac{\partial L}{\partial z_i} = 0 \qquad for\ i = 1,\ldots,n$$

(4) $$\frac{\partial L}{\partial \lambda_i} = \bar{z}_i - z_i \leq 0\ ;\quad \lambda_i(\bar{z}_i - z_i) = 0 \qquad for\ i = 1,\ldots,n$$

These equations represent restrictions on (1) that would hold if agents are profit-maximizing with m variable and n quasi-fixed inputs. Conditions (2-4) represent the first-order conditions for profit maximization. In the case of Condition (2), each fully variable input will be used at the level where the market value of its marginal product will

[6] The shadow price is the amount that profits would increase if an additional unit of z_i were used in the production process, an opportunity cost. (Chiang, 1984)

equal its marginal cost.[7] Condition (3) states that for quasi-fixed inputs, which are not used at profit-maximizing levels, there is a wedge between the input's marginal value product and marginal cost, the shadow price λ_i. λ_i represents the opportunity cost of not having access to the additional unit, an imputed price or value of the constraint. (Chiang, 1984) If λ_i equals 0, then the constraint on z_i is not binding and the input is used at the level where its marginal value product equals its marginal cost (its price). Condition (4) stipulates that the amount of z_i used can not exceed the amount available. It also stipulates a complementary slackness condition, implying that either the constraint is binding ($\bar{z}_i = z_i$), or the shadow price equals zero. Thus, one can determine if a factor input constraint is binding by testing to see if its shadow price, λ_i, equals zero.

Under some circumstances, smallholders may strive to maximize output rather than profits. Output maximization would occur in the absence of reliable supplies of food in the market, as sometimes occurs in Malawi in remote areas or in times of nationwide supply shortages. It also may occur if the price of purchasing food after harvest exceeds the cost of production and storage of crops produced within the household. Prices distorted in this manner may have arisen in Malawi due to ADMARC's policy during 1992-93 of fixing prices for food crops, licensing requirements for grain traders, and transport shortages. However, the purpose of this study is to determine whether smallholders are, in fact, profit-maximizing and if the likelihood that they maximize profits is influenced by the gender of the household head due to the presence of gender-

[7] See Appendix 2 for a full discussion of profit maximization.

specific constraints. Thus, the approach described is appropriate despite the fact that many smallholders may use output-maximizing-- rather than profit-maximizing-- decision-making strategies.

3.3 Testing for Efficiency and Constraints

The methods used in this study are as follows. First, technical efficiency of *de facto* and *de jure* female-headed households relative to male-headed households can be tested by determining whether the variables indicating headship gender cause a shift in the production function. If the null hypothesis that the parameters of the gender variables and gender-interaction variables equal 0 fails to be rejected, then there is evidence that male- and female-headed households are equally technically efficient.

Second, the parameters for the production function, equation (1), are estimated. Under typical assumptions (to be discussed later), estimation[8] of *f(x)* provides the distribution of $\beta\hat{}$, the parameters of (1). This distribution is characterized as $\beta\hat{} \sim N[\beta, \sigma^2 (x`x)^{-1}]$, where $cov(\beta\hat{})=\sigma^2 (x`x)^{-1}$. Because conditions (2), (3), and (4) cannot be tested by imposing parametric restrictions on (1), they are tested using Monte Carlo methods. Random draws from the distribution $cov(\beta\hat{})$ are taken. Actual input-output observations (the x`s) are combined with these randomly generated parameter estimates to create a confidence interval for the predicted input-output ratios for (3) under the null hypothesis that $\lambda_i = 0$.

[8] To simplify terms, the regressors described in the above section are labeled *x* and parameters of the function are labeled β here.

A comparison of the actual input-output price ratios to generated distributions shows whether the shadow price (λ_i) is significantly different from zero. If the actual input-output price ratio of an input falls within a specified confidence interval for the input's simulated distribution, then its price ratio equals its marginal product within the confidence of the study. In such a case, λ_i is not significantly different from zero, providing evidence that input use is not constrained. Should the actual price ratio fall outside the confidence interval, the shadow price is not zero, indicating the existence either of a binding constraint (ξ_i) or of allocative inefficiency. To determine if the shadow price varies by gender, which would indicate either a constraint unique to a specific headship group or gender-specific inefficiency, the simulation and testing process is executed separately for different headship categories.

Third, if shadow prices are found to be nonzero, it is necessary to differentiate between the existence of a constraint on input use and allocative inefficiency. Allocatively efficient agents use information on market conditions and production prices to employ each factor input at the profit-maximizing level where marginal value product equals marginal cost. Thus, a shadow price (λ_i) that does not equal zero could indicate allocative inefficiency rather than a factor input constraint. Consequently, a shadow price that varies with headship gender could indicate differential allocative inefficiency if certain categories of household heads are less able to choose optimal input combinations, given prevailing input and output prices.

To examine whether allocative inefficiency is causing the departure from profit-maximizing input use, the relationship between the shadow price and the set of management variables can be tested. Under the assumption that increasing the stock of management variables will improve a farmer's ability to use inputs at their profit-maximizing levels, λ_i should approach 0 as M increases. Thus, performing additional simulation and testing routines, as described above, varying the management instruments instead of headship gender, provides evidence of whether allocative inefficiency or differential constraints cause divergences .

Extensive literature exists delineating alternative methods to measure efficiency and how to decompose measurements into technical and allocative efficiency ratings. (Bravo-Ureta and Pinheiro, 1993; Dawson, 1985) Many of these studies use the frontier function approach originated by Farrell and the dual profit function approach developed by Lau and Yotopoulos. (Bravo-Ureta and Pinheiro, 1993) Although such analysis could yield important policy insights to increase smallholder productivity in future research, these models are beyond the scope of this study. This study seeks to pinpoint relative variations in production patterns among different headship categories, rather than to calculate absolute ratings of efficiency for each farm.

3.4 Data

3.4.1 The NSSA

Data for this study are drawn from the 1992-93 National Sample Survey of Agriculture (NSSA). The Malawi National Statistics Office (NSO) designed and carried out the NSSA with input from other government ministries, as well as from donors such as the World Bank. Earlier surveys were done during the 1968-69 and 1980-81 agricultural growing seasons and are supplemented by the NSO's Annual Surveys of Agriculture. The nationwide survey has three objectives. First, it is used to estimate crop production for compilation of the national accounts. Second, it aids in monitoring the effects of local agricultural extension and National Rural Development Programmes. Finally, it is used to collect data to help formulate policy to increase smallholder productivity; government officials perceive it as an important tool in measuring the effects of structural adjustment policies on smallholder farmers. (MOALD, 1993)

3.4.2 Sample Design

The country is divided into 8 Agricultural Development Districts, which are broken up into 30 Rural Development Projects (RDPs). Within the RDPs, the NSO designated 8395 Enumeration Areas (EAs), of which 600 were chosen for the survey, with each EA's probability of being selected proportional to its size. Surveyors randomly selected 20 households per EA for a total of 12,000 households. For the purpose of this survey, the NSO defines a household as "one person or a group of people generally bound

by marriage or kinship ties, who make common provision for food or simply, persons who eat together from a common pot." A household is not necessarily a family unit that resides under the same roof. (NSO 1993, p.4)

An extensive network of permanent and temporary personnel from the Ministry of Agriculture (MOA) and the NSO conducted the survey. The team consisted of 3 regional coordinators, 100 local supervisors, and 600 enumerators, for whom the government rented houses in their respective EAs and issued bicycles to facilitate coverage and accuracy. The NSO also performed a pilot survey in the 1990-91 agricultural season to test the questionnaires, as well as to troubleshoot for errors or biases likely to occur in measurement. (NSO, 1993) Although the NSO alerted local officials and issued a press release to the national media to publicize the survey, the enumerators experienced some trouble in areas where residents or police mistook them for agents of opposition political parties. The NSO was able to resolve these issues, however, and the problems did not prevent the enumerators from eventually collecting data from each household. Another problem was that, due to a severe drought during the 1991-92 growing season that led to widespread debt default, respondents were hesitant to give accurate information concerning reasons they did or did not use credit. They feared that the enumerators were collecting credit details for legal or tax purposes. For this reason, data regarding debt default are excluded from the production and gender analysis. (MOALD, 1993)

3.4.3 Survey Content

There are 6 modules to the survey: household composition, garden cultivation details, employment and assets, livestock holdings, health, and extension. This study uses responses from the household composition survey, which consists of a series of 3 personal interviews conducted in October 1992, February 1993, and June 1993. It also incorporates data from the garden survey, conducted in rounds immediately following the composition interviews, and the employment survey, which took place in July 1993.

The majority of the variables for the estimated production functions come from the garden survey. In addition to asking smallholder farmers about crops planted, seeds, rotation, and inputs, enumerators measured the size and yields of each household's cultivated plots.[9] It is important to note that enumerators did not include fallow or certain irrigated gardens (*dimba* and *dambo*) in this survey's measurements of total cultivated area (in hectares) for each household. The MOALD estimates that this practice would omit between 10 and 11 percent of total farm area. (MOALD, 1993) To measure yields for the garden survey, enumerators harvested randomly selected Yield Subplots of 50 square meters in each plot bearing either maize, rice, groundnuts, pulses, sorghum, wheat, or sunflower. (NSO, 1993)

[9] It is important to note that each household may cultivate multiple plots.

3.4.4 Variable Definitions

Maize production is chosen as the focus of the analysis because, as explained in Chapter 2, it is the crop predominately cultivated by smallholders in Malawi. Thus, the dependent variables for the production regressions are maize yields, measured in kilograms per hectare. Separate regressions are run for hybrid and local maize, as well as for fertilizer users and nonusers. These groups are divided because improved seeds and fertilizer are separate technologies that can influence the intercept and slope of the estimated production function. The independent variables in the regressions include two gender dummy variables denoting *de facto* and *de jure* female-headed households. They also include five management dummy variables: whether the household head has received any formal schooling, whether he or she has had any extension training, whether any credit[10] was used to purchase seeds or fertilizer, whether the maize plot was weeded, and whether ox labor was used in cultivation. Not only do these five variables indicate how efficiently a household's plots are managed, but combined with the gender dummy variables, they indicate whether females' ability to farm is affected by access to education; extension; credit; or by labor bottlenecks during the rainy season, when weeding becomes necessary. The environmental variable is the average monthly rainfall for the 1992-93 agricultural year, measured in centimeters at the RDP level. Person-labor days, and fertilizer, measured in kilograms of nitrogen, all are treated as variable and tested for constraints to determine whether they are actually quasi-fixed.

[10] Credit, although not in itself a contributor to yields, may insure the timeliness of farmer's access to fertilizer and seeds in Malawi. Thus, it is an indirect, but important variable in smallholder cultivation.

Landholding size, measured in hectares, is treated as a quasi-fixed variable in the production process. There is no formal land market in Malawi due to the customary land tenure characteristic of the smallholder sector. The absence of a land market precludes the existence of land prices to test for a land constraint. Further, combined with growing land scarcity and the nation's emphasis on maize as a staple subsistence crop, most smallholders have little land for diversification and produce as much maize as possible for household consumption. Thus, it is reasonable to assume that the size of the plots is constrained.

The NSSA provides all data for the production analysis except producer maize prices, fertilizer prices, rainfall data, and the number of person-days each household devoted to cultivating its crops. Hence, the study uses maize and fertilizer prices for 1992-93 from a World Bank AFTES Working Paper, "Malawi: Economic Reform and Agricultural Strategy." Monthly rainfall data at the RDP level was provided directly by the NSO.

Labor estimates are computed using NSSA household composition, hired labor, and off-farm employment data. It is assumed that each member of each household works six days a week with a total of two weeks vacation each year. This sums to 300 working days annually per household member, with working days for women and children weighted by the ratio of their *ganyu* wages (reported in the NSSA SDA module) to the *ganyu* wages received by males. The assumption of a full working year for children is not unrealistic in light of the very low enrollment rates and short enrollment periods

prevalent among smallholder children before the new political regime abolished primary school fees in 1994. Off-farm working days reported in the employment survey are also weighted and subtracted from each household's total available labor estimates. Any hired labor reported in the NSSA household composition module is added to each household's total days and the value is divided by the household's total cultivated area to obtain an estimate of the amount of labor available per hectare for the household.

3.5 Headship Categories

Research on intra-household dynamics explains that female headship is not necessarily implied by the absence of a male spouse. Nor is it negated altogether by the presence of a male spouse. Dey (1984) argues that although policy makers and development planners commonly stereotype the male spouse as the household head, often in sub-Saharan Africa "men and women have separate but complementary roles and responsibilities for agricultural production." (p.11) She argues that this stereotyping ignores female spouses' roles as "own-account farmers and business women." (p.12) Moser (1993) writes that the idea of a household head, "normally assumed to be a male," may be a "figment of the statistician's imagination" due to the multiple roles women fulfill within the household. (p.16) Her review of gender in agricultural development questions the designation of headship in national household surveys, in particular.

However, for this study, the absence of a husband is the major criterion for female headship: intra-household decision-making complexities are ignored. Thus, this study analyzes maize production according to three basic, but widely used categories: male-headed households, *de jure* female-headed households, and *de facto* female-headed households. (Gladwin, 1992; Kennedy and Peters, 1992; Due, 1991; Lele, 1991; World Bank, 1991) In *de jure* households, a female is the household head because she has never married, or is widowed, divorced, or separated. In *de facto* households, the male spouse is polygamous or leaves the farm for periods of one month or longer, often migrating in search of wage labor. Some researchers include women who are separated from their husbands in the *de facto* category (Due, 1991), but as marital separation is often a legal or permanent state, or may reflect abandonment by the spouse, this study designates separated women as *de jure* household heads.

3.6 Summary Statistics

Averages of the survey data reveal that female-headed households are not homogeneous entities. *De jure* female-headed households have approximately 200 fewer days of available labor for household production per year than their *de facto* female-headed counterparts, who often have husbands employed elsewhere as wage laborers (Table 3.1). *De jure* female heads of household are also an average of 48 percent less likely to receive extension training and 37 percent less likely to have any formal schooling than *de facto* female heads. *De facto* female headed households achieve

Table 3.1
Summary Statistics at the Household Level

Gender Category	Maize Variety	Nitrogen Application	Total Area Cultivated (ha)	Available Labor (person-days/ha)	HH with Education (%)	HH received Extension Training (%)
MHH	Hybrid Maize	Fertilizer	1.17	967	47	39
		No Fertilizer	1.13	934	72	34
	Local Maize	Fertilizer	1.09	923	47	34
		No Fertilizer	0.97	885	68	26
De Facto FHH	Hybrid Maize	Fertilizer	1.11	1072	69	54
		No Fertilizer	1.36	1028	67	45
	Local Maize	Fertilizer	1.05	1024	51	36
		No Fertilizer	1.12	963	53	35
De Jure FHH	Hybrid Maize	Fertilizer	0.92	867	38	24
		No Fertilizer	0.81	818	43	18
	Local Maize	Fertilizer	0.83	841	35	20
		No Fertilizer	0.66	744	34	11

Table 3.2
Summary Statistics at the Plot Level

Gender Category	Maize Variety	Nitrogen Application	Yields kg/ha	Plot Size ha	Fertilizer Nitrogen kg/ha	Credit Used to Purchase Inputs (%)	Manure Applied (%)	Oxen Used to Plow Plot (%)	Plot Weeded (%)
MHH	Hybrid Maize	Fertilizer	2627	0.44	123	60	12	4	99
		No Fertilizer	2061	0.42	0	30	14	4	79
	Local Maize	Fertilizer	1700	0.44	100	32	14	2	99
		No Fertilizer	1411	0.42	0	8	14	3	90
De Facto FHH	Hybrid Maize	Fertilizer	2570	0.53	109	68	14	7	96
		No Fertilizer	2253	0.54	0	30	14	7	51
	Local Maize	Fertilizer	1781	0.56	118	35	13	2	99
		No Fertilizer	1468	0.53	0	15	15	5	66
De Jure FHH	Hybrid Maize	Fertilizer	2204	0.41	120	56	19	2	98
		No Fertilizer	1804	0.33	0	21	14	4	72
	Local Maize	Fertilizer	1681	0.42	100	30	19	2	99
		No Fertilizer	1339	0.37	0	5	15	2	88

Table 3.3

Percentage of Households Using Hybrid Seeds or Applying Fertilizer*

	Hybrid Maize		Local Maize	
	Fertilizer	No Fertilizer	Fertilizer	No Fertilizer
All Households	17.3%	25.1%	17.9%	59.4%
MHH	20.9%	27.2%	20.2%	57.0%
De Facto FHH	14.0%	42.3%	16.0%	69.8%
De Jure FHH	10.7%	18.9%	13.6%	62.0%

* This table shows the percent of households in each headship gender category adopting each type of technology regime. Each household may adopt more than one technology regime, so percentages do not sum to 100.

production levels of between 100 and 449 kilograms more maize per hectare than *de jure* female-headed households (Table 3.2) and have higher rates of fertilizer use (Table 3.3). They are nearly twice as likely to adopt hybrid seeds. Clearly, *de facto* female-headed households operate in a much more input-intensive production regime than *de jure* female-headed households with more access to information and training. Thus, it is important to differentiate between these two groups in discussing maize production.

The average yields realized on male-headed smallholder farms are comparable to those on *de facto* female-headed farms with the exception of hybrid maize plots cultivated without fertilizer, for which yields on the female-headed farms are about 200 kilograms higher per hectare. *De facto* female heads of household have a much higher rate of adoption for hybrid seeds grown without fertilizer, as 42.7% adopt, compared to 27.2% of males. However, *de facto* female household heads are less likely to use fertilizer regardless of whether they are cultivating a local or hybrid variety. A higher proportion of *de facto* female-headed households also cultivate local maize without fertilizer. It is possible that *de jure* female-headed households facing cash or credit constraints that prevent the use of both improved seeds and fertilizer tend to apply their funds to hybrid seeds, while male-headed households more often choose fertilizer. NSSA data indicate that 45 percent of *de facto* female household heads receive extension support, as compared to 34 percent of male household heads, while *de facto* female and male household heads growing local varieties with fertilizer have a more comparable incidence of extension contact (36 and 34 percent, respectively). Thus, a higher

incidence of extension contact could explain the higher hybrid adoption rate for *de facto* female-headed households.

3.7 Empirical Estimation and Testing

The analysis uses a translog production function to estimate the maize production of smallholder producers separately for hybrid and local growers, as well as those who use or do not use fertilizer. Using the variables listed in Table 3.4, with t equaling the number of observations, the function is expressed as

$$
\begin{aligned}
\ln y_t = {} & \alpha_0 + \sum_{b=1}^{2} \alpha_b g_{bt} + \sum_{d=1}^{8} \beta_d m_{dt} + \sum_{h=1}^{2} \gamma_h \ln v_{ht} + \delta \ln z_t + \zeta \ln e_t \\
& + \tfrac{1}{2} \sum_{b=1}^{2} \sum_{d=1}^{8} \eta_{bd} g_{bt} m_{dt} + \tfrac{1}{2} \sum_{b=1}^{2} \sum_{h=1}^{2} \vartheta_{bh} g_{bt} \ln v_{ht} + \tfrac{1}{2} \sum_{b=1}^{2} \iota_b g_{bt} \ln z_t \\
& + \tfrac{1}{2} \sum_{b=1}^{2} \kappa_b g_{bt} \ln e + \tfrac{1}{2} \sum_{d=1}^{8} \sum_{e=1}^{8} \mu_{de} m_{dt} m_{et} + \tfrac{1}{2} \sum_{d=1}^{8} \sum_{h=1}^{2} \nu_{dh} m_{dt} \ln v_{ht} \\
& + \tfrac{1}{2} \sum_{d=1}^{8} \xi_d m_{dt} \ln z_t + \tfrac{1}{2} \sum_{d=1}^{8} o_d m_{dt} \ln e_t + \tfrac{1}{2} \sum_{h=1}^{2} \sum_{i=1}^{2} \tau_{hi} \ln v_{ht} \ln v_{it} \\
& + \tfrac{1}{2} \sum_{h=1}^{2} \upsilon_h \ln v_{ht} \ln z_t + \tfrac{1}{2} \sum_{h=1}^{2} \varphi_h \ln v_{ht} \ln e_t + \tfrac{1}{2} \chi (\ln z_t)^2 \\
& + \tfrac{1}{2} \psi \ln z_t \ln e_t + \tfrac{1}{2} \omega (\ln e_t)^2 + \varepsilon_t
\end{aligned}
\tag{5}
$$

for $d \neq e$.

The translog is chosen because it is sufficiently flexible and is a second-order Taylor Series approximation. Because the derivatives of a Taylor Series approximation converge to the derivatives of the underlying production function within a region of

Table 3.4

Variables Used in Maize Production Function Estimation

Continuous Variables	
v_1	nitrogen applied per hectare (kg)
v_2	available labor per hectare (person-days)
z	area of plot (ha)
e	total rainfall for the 1992-93 agricultural year at the RDP level (cm)
Dummy Variables[11]	
g_1	*de jure* female-headed household
g_2	*de facto* female-headed household
m_1	household head received formal education
m_2	manure applied to plot
m_3	household head received some extension training or services
m_4	plot was weeded
m_5	credit used to buy seeds, fertilizer, or pesticides for the plot
m_6	oxen labor used to plow the plot
m_7	household located in the northern region
m_8	household located in the central region

[11] "Yes" = 1, "No" = 0.

convergence surrounding the point of approximation. Thus, it is a good choice for testing profit maximization, which involves testing first-order derivatives. By using the translog form of the approximation, the region of convergence is expanded to an infinitely large cube, eliminating the need to disqualify data that might arise if a quadratic or Generalized Leontief form is used. (Driscoll, 1994)

3.8 Testing for Constraints and Efficiency

Three principal tests need to be conducted to determine if there is evidence of (1) gender-differentiated technical efficiency, (2) gender-differentiated nonzero shadow prices, and (3) nonzero shadow prices due to allocative inefficiency. First, the technical efficiency of female-headed households relative to male-headed households is examined by testing whether the gender variables shift the intercept of the production function. The null hypothesis,

$$H_0 : \alpha_b = 0,$$

is tested using an F-test (Koutsoyiannis, 1977). Should the null hypothesis fail to be rejected, the production function does not shift due to the dummy variables, indicating that household heads of differing gender are equally technically efficient.

Second, Monte Carlo simulation is used to test for resource constraints. A Hausmann test of parametric restrictions is not used because it may yield an inconclusive (negative) result and because it does not allow detailed examination of gender dynamics possibly influencing λ_i (Kennedy, 1985). Having obtained parameter estimates and a

variance-covariance matrix, the simulation generates 100 parameter vectors from the model's multivariate, normal distribution. For each parameter vector, actual factor-input usage observations are substituted into the first-order equations,

$$(6)\quad \frac{w_h}{p_y} = \frac{\hat{y}_t}{v_h}(\hat{\alpha}_h + \tfrac{1}{2}\sum_{h=1}^{2}\hat{\vartheta}_{hh}g_{it} + \tfrac{1}{2}\sum_{d=1}^{6}\hat{\nu}_{dh}m_{dt} + \sum_{i=1}^{2}\hat{\tau}_{hi}\ln v_{it} + \tfrac{1}{2}\hat{\upsilon}_h \ln z_t + \tfrac{1}{2}\hat{\varphi}_h \ln e_t) + \varpi_t,$$

to obtain a numeric distribution for the model's predicted input-output price ratio.[12] The actual ratios of input to output prices then are tested to determine if they lie within a 95 percent confidence interval of the mean of the predicted distributions. Inputs with normalized prices that lie within this interval have shadow prices equal to 0; therefore, they are unconstrained and efficiently allocated. To determine whether the impediment to profit-maximizing input use is gender-specific, the process of simulation and testing the input-output price ratios is carried out separately for each headship category.

To determine whether a resource constraint or allocative efficiency is preventing profit-maximizing input use, the simulation process is repeated separately for each headship category, with observations sorted according to whether the household head has received any education or extension training. Extension and education are the two management variables included in the estimated production function that could increase a farmer's ability to ascertain input and output prices and allocate inputs at optimal levels. The existence of allocative inefficiency would cause shadow prices to approach zero for

[12] ϖ_t represents error in the estimation of the marginal product.

households having education or extension training. If there is no relationship between profit-maximizing input use and these management variables, resources with nonzero shadow prices are considered quasi-fixed. Where the shadow price of a quasi-fixed resource varies by headship gender, a gender-specific resource constraint is at work.

3.8 Summary of Methods

Despite extensive literature explaining why gender-specific constraints may affect production in Malawi's rural economy, there have been no studies based on the economic theory of production that determine whether or not such constraints in fact exist. This study uses the first order conditions for profit-maximization to test for gender-specific constraints. To this end, local and hybrid maize production functions are estimated and a simulation is run on the first-order equations for profit maximization, differentiating for headship gender. This simulation generates a distribution for the model's prediction of marginal product, which should equal the actual input-output price ratio for variable inputs used by a profit-maximizing farmer. Where the actual price ratio does not fall within a given confidence interval of the distribution, a nonzero shadow price is evident. In this case, a second simulation is performed, differentiating for gender, education, and extension support, to determine if a constraint exists, or if allocative inefficiency is impeding profit maximization for a particular gender group. The relative technical efficiency of headship gender groups is also compared by examining shifts in the intercepts of the production functions caused by gender variables. The following

chapter further illustrates the estimation, specification testing, and simulation of the maize production functions.

Chapter 4

Estimation and Testing

4.1 Overview

As described in Chapter 3, this study tests the first-order conditions for profit-maximization to determine whether female-headed households face unique constraints to increased maize production. It also compares the technical and allocative efficiency of male- and female-headed households. The results of the production function estimation are presented and analyzed. First, the process of testing the specification of the production function is described. The parameters of the final regressions are shown and implications for technical efficiency are discussed. Third, the results of tests for nonzero shadow prices and allocative inefficiency are presented.

4.2 Estimation of the Production Functions

Because hybrid seeds and fertilizers are each considered separate technologies, the production function parameters are estimated separately for hybrid maize growers who use fertilizer, hybrid maize growers who do not use fertilizer, local maize growers who use fertilizer, and local maize growers who do not use fertilizer.[13] Ordinary least-squares (OLS) is used in estimation. To begin, the regressors are the same for each production

[13] The determinants of adoption of different technologies are not examined. Instead, the study focuses on productive efficiency and constraints conditioned on the adoption of a specific technology regime.

function, except for fertilizer nitrogen, which is omitted in regressions estimating production for non-fertilizer users. It is important to note that each observation in the regressions represents a plot. A household may cultivate more than one maize plot and use a different technology on each plot. Hence, whereas a total of 10,239 households are represented in the four regressions, there are a total of 54,030 observations. Data for yields (kg/ha), plot size (ha), fertilizer nitrogen applied (kg/ha), manure application, ox labor usage, credit usage, and weeding are all recorded at the plot level. (See variable descriptions and summary statistics in Chapter 3.) The education, extension training, and gender of the household head, as well as the amount of labor the household has per hectare of total cultivated land, are household-level variables. These variables are repeated for each observation in households cultivating multiple maize plots.

4.3 Specification Testing

Specification tests for normality of the residuals, homoskedasticity, and linearity in the conditional mean are performed for each of the four regressions. Skewness, kurtosis, and D'Agostino-Pearson tests are calculated using the $\sqrt{b_1}$, b_2, and K^2 statistics discussed by D'Agostino, Belanger, and D'Agostino (1990). All three statistics reject the hypothesis of normality for the residuals in all four regressions (Table 4.1). Therefore, the Central Limit Theorem is invoked to assert that a consistent parameter estimates converge to a normal distribution asymptotically, so that the significance of the parameter estimates can be tested using statistics derived from the normal distribution.

Table 4.1
Tests for Normality of the Residuals

Maize Variety	Nitrogen Application	Number of Observations	Skew	Probability >Chi-sq	Kurtosis	Probability >Chi-sq	K-Squared	Probability >Chi-sq
Hybrid Maize	Fertilizer	4943	-26.0206	0.0000	11.6667	0.0000	813.1860	0.0000
	No Fertilizer	5077	-20.8035	0.0000	3.8519	0.0001	447.6980	0.0000
Local Maize	Fertilizer	6119	-19.8746	0.0000	6.6838	0.0000	439.6710	0.0000
	No Fertilizer	17127	-25.3224	0.0000	-3.6741	0.0002	654.7230	0.0000

Table 4.2

Results of RESET Test of Functional Form*

Maize Variety	Nitrogen Application	Adjusted R-Squared	F-Value	Probability >F
Hybrid Maize	Fertilizer	0.1510	0.1510	1.0000
	No Fertilizer	0.1000	0.2830	1.0000
Local Maize	Fertilizer	0.1610	0.1610	1.0000
	No Fertilizer	0.6520	0.6520	1.0000

* The regression is expressed as

$$\varepsilon_t = \alpha_0 + \sum_{b=1}^{2} \alpha_b g_{bt} + \sum_{d=1}^{8} \beta_d m_{dt} + \sum_{h=1}^{2} \gamma_h \ln v_{ht} + \delta \ln z_t + \zeta \ln e_t$$

$$+\frac{1}{2}\sum_{b=1}^{2}\sum_{d=1}^{8} \eta_{bd} g_{bt} m_{dt} + \frac{1}{2}\sum_{b=1}^{2}\sum_{h=1}^{2} \vartheta_{bh} g_{bt} \ln v_{ht} + \frac{1}{2}\sum_{b=1}^{2} \iota_b g_{bt} \ln z_t$$

$$+\frac{1}{2}\sum_{b=1}^{2} \kappa_b g_{bt} \ln e + \frac{1}{2}\sum_{d=1}^{8}\sum_{e=1}^{8} \mu_{de} m_{dt} m_{et} + \frac{1}{2}\sum_{d=1}^{8}\sum_{h=1}^{2} \nu_{dh} m_{dt} \ln v_{ht}$$

$$+\frac{1}{2}\sum_{d=1}^{8} \xi_d m_{dt} \ln z_t + \frac{1}{2}\sum_{d=1}^{8} o_d m_{dt} \ln e_t + \frac{1}{2}\sum_{h=1}^{2}\sum_{i=1}^{2} \tau_{hi} \ln v_{ht} \ln v_{it}$$

$$+\frac{1}{2}\sum_{h=1}^{2} \upsilon_h \ln v_{ht} \ln z_t + \frac{1}{2}\sum_{h=1}^{2} \varphi_h \ln v_{ht} \ln e_t + \frac{1}{2}\chi(\ln z_t)^2$$

$$+\frac{1}{2}\psi \ln z_t \ln e_t + \frac{1}{2}\omega(\ln e_t)^2 + \hat{y}_t^2 + \hat{y}_t^3$$

Table 4.3

Results of White's Test for Heteroskedasticity*

Maize Variety	Nitrogen Application	Adjusted R-Squared	F-Value	Probability >F
Hybrid Maize	Fertilizer	0.0363	3.216	0.0001
	No Fertilizer	0.0296	4.009	0.0001
Local Maize	Fertilizer	0.0382	3.432	0.0001
	No Fertilizer	0.0144	4.478	0.0001

* The regression is expressed as

$$\begin{aligned}
\varepsilon^2_t = {} & \alpha_0 + \sum_{b=1}^{2} \alpha_b g_{bt} + \sum_{d=1}^{8} \beta_d m_{dt} + \sum_{h=1}^{2} \gamma_h \ln v_{ht} + \delta \ln z_t + \zeta \ln e_t \\
& + \frac{1}{2}\sum_{b=1}^{2}\sum_{d=1}^{8} \eta_{bd} g_{bt} m_{dt} + \frac{1}{2}\sum_{b=1}^{2}\sum_{h=1}^{2} \vartheta_{bh} g_{bt} \ln v_{ht} + \frac{1}{2}\sum_{b=1}^{2} \iota_b g_{bt} \ln z_t \\
& + \frac{1}{2}\sum_{b=1}^{2} \kappa_b g_{bt} \ln e + \frac{1}{2}\sum_{d=1}^{8}\sum_{e=1}^{8} \mu_{de} m_{dt} m_{et} + \frac{1}{2}\sum_{d=1}^{8}\sum_{h=1}^{2} \nu_{dh} m_{dt} \ln v_{ht} \\
& + \frac{1}{2}\sum_{d=1}^{8} \xi_d m_{dt} \ln z_t + \frac{1}{2}\sum_{d=1}^{8} o_d m_{dt} \ln e_t + \frac{1}{2}\sum_{h=1}^{2}\sum_{i=1}^{2} \tau_{hi} \ln v_{ht} \ln v_{it} \\
& + \frac{1}{2}\sum_{h=1}^{2} \upsilon_h \ln v_{ht} \ln z_t + \frac{1}{2}\sum_{h=1}^{2} \varphi_h \ln v_{ht} \ln e_t + \frac{1}{2}\chi(\ln z_t)^2 \\
& + \frac{1}{2}\psi \ln z_t \ln e_t + \frac{1}{2}\omega(\ln e_t)^2 + \hat{y}_t^2 + \hat{y}_t^3.
\end{aligned}$$

A RESET test regressing the residuals on the original regressors, the squared predicted yields, and the cubed predicted yields is performed to test the functional form. The test shows no correlation between the regressors and the residuals (Table 4.2), implying that the model is linear in the conditional mean. A RESET version of White's tests is used to determine if the variance of the conditional distribution is constant. Regressing the squared residuals on the original regressors, the squared predicted yields, and the cubed predicted yields reveals that a small systematic relationship exists between the model variance and the regressors for both fertilizer users and non-users growing hybrid and local maize (Table 4.3). Due to the existence of heteroskedastic variances, White's correction[14] is used to generate consistent estimates of parameter variances. This correction is used to test the significance of individual parameters and to test the significance of sets of second-order variables to reduce the regressions (Table 4.4a-d).

Heteroskedasticity does not affect the means of the OLS parameter estimates, as they are asymptotically unbiased under assumptions of asymptotic normality and linearity. However, it does imply that the variances of the parameter estimates are biased. Unfortunately, the size of the data subsets and limited computer resources preclude the use of White's procedure to construct a consistent estimate of the variance-covariance matrix for the simulation of the first-order equations. Using the uncorrected matrix with biased variance estimates thus distorts the generated distributions for the predicted marginal products of labor and fertilizer. However, the fact that none of the R-squared

[14] For White's correction, the squared residuals of the regression are substituted for the estimated conditional variance to calculate a consistent estimate of the parameter variances. (Maddala, 1990)

Table 4.4a

Model Regressors and Parameter Estimates: Hybrid Maize Plots with Fertilizer **N=4943** **Adjusted R^2=0.12**

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chisq
De_Jure FHH (G1)	-0.239902	0.1118	0.7381
De_Facto FHH (G2)	-0.024911	0.2189	0.6399
Education of HH Head (M1)	-0.025323	1.0274	0.3108
Manure Application (M2)	-2.92491	14.433	0.0001
Extension Training (M3)	-1.723676	10.7283	0.0011
Weeding (M4)	4.440858	1.7722	0.1831
Credit Used (M5)	-0.357332	0.4942	0.482
Oxen Labor Used (M6)	-3.772778	4.5599	0.0327
Monthly Rainfall-cm (E)	3.897691	3.0744	0.0795
Fertilizer Nitrogen-kg/ha (V1)	0.818011	6.9605	0.0083
Labor-man days (V2)	-0.303885	0.8222	0.3645
Plot Size-ha (Q1)	1.281977	13.3272	0.0003
Northern Region (R1)	2.855023	6.8621	0.0088
Central Region (R2)	0.648203	1.1115	0.2917
G1*M2	-0.104309	1.7413	0.187
G1*M3	0.453602	52.6826	0
G1*M4	-0.446297	18.8369	0
G1*M5	-0.21868	1301793	0.0003
G1*M6	0.018864	0.00913	0.9239
G1*E	-0.014044	0.021	0.8848
G1*V1	0.043364	1.2677	0.2602
G1*V2	0.075712	3.8475	0.0498
G1*Q1	0.051572	1.643	0.1999
G1*R1	-0.016749	0.0207	0.8856
G1*R2	0.023785	0.1395	0.7088
M2*M3	-0.239945	13.5239	0.0002
M2*M4	1.320705	32.4682	0
M2*M5	0.140347	4.8204	0.0281
M2*M6	-0.000256	0	0.9988
M2*E	0.152426	2.3584	0.1246
M2*V1	0.034207	1.0406	0.3077
M2*V2	0.028185	0.4972	0.4807
M2*Q1	-0.07151	2.2336	0.135
M2*R1	0.276894	3.7026	0.0543
M2*R2	0.045549	0.5192	0.4712
M3*M4	0.042565	0.04506	0.8319
M3*M5	-0.140601	10.0561	0.0015
M3*M6	-0.000566	0	0.9958
M3*E	0.219445	11.5054	0.0007
M3*V1	0.025511	1.0927	0.2959
M3*V2	0.034347	1.473	0.2249
M3*Q1	0.087782	11.0232	0.0009
M3*R1	-0.160823	3.7536	0.0527
M3*R2	-0.072759	2.001	0.1572
M4*M5	0.739663	18.8337	0
M4*M6	-0.595615	5.4262	0.0198
M4*E	-0.48817	2.51	0.1131
M4*V1	-0.790288	47.5082	0
M4*V2	0.283643	3.592	0.0581
M4*Q1	-0.240552	3.328	0.0681
M4*R1	-0.001892	0.0001	0.9937
M4*R2	-0.117972	0.2905	0.5899
M5*M6	-0.016446	0.016	0.8992
M5*E	-0.081432	1.5763	0.2093
M5*V1	-0.062579	6.3683	0.0116
M5*V2	0.074813	8.7698	0.0031
M5*Q1	-0.050947	3.6181	0.0572
M5*R1	0.137709	2.9642	0.0851
M5*R2	0.094018	4.0482	0.0442
M6*E	0.40367	3.8478	0.0498
M6*V1	-0.005181	0.00456	0.9462
M6*V2	0.280139	23.3968	0
M6*Q1	0.14478	3.8825	0.0488
M6*R1	-0.262866	4.3515	0.037
E*E	-0.182511	1.3784	0.2404
E*V1	0.036927	0.901	0.3425
E*V2	-0.140901	11.0072	0.0009
E*Q1	-0.142952	11.2517	0.0008
E*R1	-0.425702	8.522	0.0035
E*R2	-0.198558	6.4912	0.0108
V1*V1	0.019015	6.4825	0.0109
V1*V2	-0.057168	18.7754	0
V1*Q1	0.034484	4.8635	0.0274
V1*R1	0.029333	0.3959	0.5292
V1*R2	0.177583	44.0232	0
V2*V2	0.080597	44.8927	0
V2*Q1	-0.001252	0.0052	0.9422
V2*R1	0.019996	0.2115	0.6456
V2*R2	0.048916	2.7689	0.0961
Q1*Q1	0.038904	11.9314	0.0006
Q1*R1	0.03233	0.4986	0.4801
Q1*R2	0.059097	3.7731	0.0521

Table 4.4b

Model Regressors and Parameter Estimates: Local Maize With Fertilizer

N=5077 Adjusted R^2=0.11

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chi-sq
De_Jure FHH (G1)	-2.321629	11.9514	0.0005
De_Facto FHH (G2)	0.015723	0.0835	0.7727
Education of HH Head (M1)	0.021266	0.9182	0.3379
Manure Application (M2)	-1.92273	6.8419	0.0089
Extension Training (M3)	-0.534834	1.0531	0.3048
Weeding (M4)	5.052117	6.2069	0.0127
Credit Used (M5)	0.398922	0.5229	0.4696
Oxen Labor Used (M6)	-1.07247	0.243	0.622
Monthly Rainfall-cm (E)	-9.087633	22.168	0
Fertilizer Nitrogen-kg/ha (V1)	0.475546	2.428	0.1192
Labor-man days (V2)	-0.63964	2.6323	0.1047
Plot Size-ha (Q1)	0.057836	0.0161	0.8992
Northern Region (R1)	-0.756662	0.4386	0.5078
Central Region (R2)	0.183294	0.1057	0.7451
G1*M2	-0.027128	0.1742	0.6764
G1*M3	0.133888	5.7304	0.0167
G1*M4	0.508343	3.1657	0.0752
G1*M5	0.041343	0.6956	0.4043
G1*M6	-0.029316	0.0312	0.8598
G1*E	0.173125	4.9375	0.0263
G1*V1	-0.029768	1.2174	0.2699
G1*V2	0.092853	7.9897	0.0047
G1*Q1	-0.114111	8.2776	0.004
G1*R1	-0.098768	0.9779	0.3227
G1*R2	-0.079688	2.4145	0.1202
M2*M3	0.20886	12.9097	0.0003
M2*M4	-0.488844	2.5462	0.1106
M2*M5	0.039048	0.5679	0.4511
M2*M6	-1.000541	24.6274	0
M2*E	0.290297	9.3023	0.0023
M2*V1	-0.002751	0.0076	0.9306
M2*V2	0.038627	1.0228	0.3119
M2*Q1	0.016237	0.1099	0.7403
M2*R1	0.44467	13.5891	0.0002
M2*R2	0.001897	0.0012	0.9727
M3*M4	0.377994	9.2753	0.0023
M3*M5	0.02446	0.3938	0.5303
M3*M6	-0.051817	0.1448	0.7036
M3*E	-0.031677	0.2214	0.638
M3*V1	0.002176	0.0084	0.9271
M3*V2	0.023443	0.7433	0.3886
M3*Q1	-0.045209	20.729	0.1499
M3*R1	0.256369	8.5319	0.0035
M3*R2	0.185582	13.7308	0.0002
M4*M5	-0.369492	2.6035	0.1066
M4*E	-0.463271	1.7577	0.1849
M4*V1	0.138894	2.0697	0.1502
M4*V2	-0.218811	3.7143	0.0539
M4*Q1	0.477554	7.4784	0.0062
M4*R1	-0.692072	3.6115	0.0574
M4*R2	-0.45095	5.5686	0.0183
M5*M6	-0.674406	17.064	0
M5*E	-0.055897	0.7813	0.3768
M5*V1	-0.022759	1.1666	0.2801
M5*V2	0.071699	7.5713	0.0059
M5*Q1	-0.082427	6.9314	0.0085
M5*R1	0.313666	11.0525	0.0009
M5*R2	0.055761	1.7073	0.1913
M6*E	0.144446	0.1661	0.6836
M6*V1	0.06341	0.5533	0.457
M6*V2	0.000273	0	0.9977
M6*Q1	-0.089906	0.5246	0.4689
M6*R1	0.102249	0.1934	0.6601
E*E	0.624821	22.7798	0
E*V1	-0.102484	8.0744	0.0045
E*V2	0.164378	12.4236	0.0004
E*Q1	-0.124527	5.3014	0.0213
E*R1	-0.014651	0.01075	0.9174
E*R2	0.032444	0.1997	0.6549
V1*V1	0.018105	7.6311	0.0057
V1*V2	0.004675	0.1033	0.7479
V1*Q1	0.027516	2.7402	0.0979
V1*R1	0.086296	3.1963	0.738
V1*R2	0.106002	18.7426	0
V2*V2	-0.035271	9.0083	0.0027
V2*Q1	0.028643	2.04808	0.1524
V2*R1	0.176182	10.3802	0.0013
V2*R2	-0.008917	0.087	0.768
Q1*Q1	-0.008893	0.3002	0.5838
Q1*R1	0.061985	0.9647	0.326
Q1*R2	0.224089	43.6988	0

Table 4.4c

Model Regressors and Parameter Estimates: Hybrid Maize with No Fertilizer N=6119 Adjusted R^2=0.14

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chi-sq
De_Jure FHH (G1)	-0.063799	7.3356	0.0068
De_Facto FHH (G2)	-0.060279	1.619	0.2032
Education of HH Head (M1)	0.068372	10.2346	0.0014
Manure Application (M2)	-2.316524	12.3466	0.0004
Extension Training (M3)	0.443117	0.9119	0.3396
Weeding (M4)	-0.101802	0.04239	0.8369
Credit Used (M5)	-0.829835	3.4093	0.0648
Oxen Labor Used (M6)	-2.018426	2.5406	0.111
Monthly Rainfall-cm (E)	-5.739997	8.3077	0.0039
Labor-man days (V2)	-0.64504	5.5989	0.018
Plot Size-ha (Q1)	0.235813	0.8321	0.3617
Northern Region (R1)	2.026463	4.8915	0.027
Central Region (R2)	0.399266	0.5868	0.4437
M2*M3	-0.015603	0.0607	0.8054
M2*M4	-0.060898	0.9646	0.326
M2*M5	0.001066	0.0003	0.9864
M2*M6	-0.580277	12.8297	0.0003
M2*E	0.244031	7.0427	0.008
M2*V2	0.086777	8.5247	0.0035
M2*Q1	-0.061411	4.9103	0.0267
M2*R1	0.239153	6.2424	0.0125
M2*R2	0.056046	0.8381	0.36
M3*M4	0.012404	0.0692	0.7925
M3*M5	0.018657	0.1948	0.6589
M3*M6	0.360165	10.4354	0.0012
M3*E	-0.101329	2.7406	0.0978
M3*V2	0.054344	3.203	0.0735
M3*Q1	-0.039625	1.3992	0.2368
M3*R1	-0.23275	8.7285	0.0031
M3*R2	0.011669	0.0498	0.8234

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chi-sq
M4*M5	0.137188	8.6296	0.0033
M4*M6	0.109537	0.5803	0.4462
M4*E	-0.015994	0.0585	0.8088
M4*V2	0.034738	1.4986	0.2209
M4*Q1	-0.000894	0.0011	0.9739
M4*R1	-0.054822	0.5335	0.4652
M4*R2	-0.247914	21.7665	0
M5*M6	0.084206	0.5363	0.464
M5*E	0.141888	5.6971	0.017
M5*V2	-0.033673	1.4629	0.2265
M5*Q1	-0.030259	1.0771	0.2993
M5*R1	0.159897	4.416	0.0356
M5*R2	0.25384	23.4299	0
M6*E	0.145733	0.8012	0.3707
M6*V2	0.213117	13.4217	0.0002
M6*Q1	-0.269832	13.2042	0.0003
M6*R1	-0.583865	14.3263	0.0002
M6*R2	-1.084341	23.6637	0
E*E	0.396443	8.1623	0.0043
E*V2	0.017532	0.2614	0.6091
E*Q1	0.044355	1.6875	0.1939
E*R1	-0.174487	2.1637	0.1413
E*R2	-0.064283	0.854	0.3554
V2*V2	0.031151	8.6216	0.0033
V2*Q1	-0.053181	16.3357	0.0001
V2*R1	-0.088031	3.4285	0.0641
V2*R2	0.055052	4.034	0.0446
Q1*Q1	0.048315	51.853	0
Q1*R1	0.094898	3.4406	0.0636
Q1*R2	-0.011194	0.1835	0.6683

Table 4.4d

Model Regressors and Parameter Estimates: Local Maize with No Fertilizer N=17127 Adjusted R^2=0.07

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chi-sq
De_Jure FHH (G1)	-0.217759	0.5948	0.4406
De_Facto FHH (G2)	-0.019676	0.4571	0.499
Education of HH Head (M1)	-0.162919	0.358	0.5496
Manure Application (M2)	-2.66537	36.4635	0
Extension Training (M3)	0.24397	0.7034	0.4016
Weeding (M4)	0.003773	0.0529	0.818
Credit Used (M5)	-0.804584	3.3876	0.0657
Oxen Labor Used (M6)	2.653456	7.672	0.0056
Monthly Rainfall-cm (E)	-5.775195	32.679	0
Labor-man days (V2)	-0.267177	2.3686	0.1238
Plot Size-ha (Q1)	0.707273	19.8066	0
Northern Region (R1)	1.749958	14.4594	0.0001
Central Region (R2)	-2.615813	85.6549	0
G1*M1	-0.063442	4.6317	0.0314
G1*M2	0.121555	13.5553	0.0002
G1*M3	-0.013924	0.1577	0.6913
G1*M5	0.0111875	5.0178	0.0251
G1*M6	-0.045469	0.576	0.6172
G1*E	-0.005959	0.0257	0.8725
G1*V2	0.033602	4.1764	0.041
G1*Q1	0.012991	0.7446	0.3882
G1*R1	0.057174	1.8715	0.1713
G1*R2	-0.028578	1.1748	0.2784
M1*M2	0.002628	0.0061	0.9379
M1*M3	0.028793	1.0795	0.2988
M1*M5	-0.062935	2.6743	0.102
M1*M6	-0.19982	8.3542	0.0038
M1*E	0.061891	3.0331	0.0816
M1*V2	-0.045152	7.6389	0.0057
M1*Q1	-0.08029	30.5725	0
M1*R1	0.057051	2.5213	0.1123
M1*R2	0.060374	4.8179	0.0282
M2*M3	0.06851	3.6437	0.0563
M2*M5	-0.079576	1.5011	0.2205
M2*M6	-0.029586	0.1173	0.7319

Regressor	Parameter Estimate	Chi-sq Value	Probability >Chi-sq
M2*E	0.310653	35.537	0
M2*V2	-0.013651	0.5084	0.4758
M2*Q1	-0.037092	4.3946	0.0361
M2*R1	-0.086392	66.3442	0
M2*R2	0.03528	5.1138	0.0237
M3*M5	-0.048105	4.7511	0.0293
M3*M6	0.003537	0.283	0.5948
M3*E	-0.033949	1.5553	0.2021
M3*V2	0.025839	0.044	0.8339
M3*Q1	0.117928	5.5752	0.0182
M3*R1	0.161703	0.4468	0.5039
M3*R2	0.128475	14.9989	0.0001
M5*M6	0.020102	3.0362	0.0814
M5*E	0.014559	4.5797	0.0324
M5*V2	-0.105239	0.5194	0.4711
M5*Q1	0.153936	0.4971	0.4808
M5*R1	-0.314981	1.3611	0.2433
M5*R2	-0.028201	0.0063	7.4551
M6*E	0.061368	5.5369	0.0186
M6*V2	0.10009	0.5302	0.4665
M6*Q1	-0.340474	3.4557	0.063
M6*R1	0.341257	0.5497	0.4584
M6*R2	0.078949	5.5316	0.0187
E*E	-0.062959	23.2159	0
E*V2	-0.328361	13.9423	0.0002
E*Q1	0.397017	8.9056	0.0028
E*R1	-0.022551	32.3017	0
E*R2	-0.023035	110.1835	0
V2*V2	0.059535	13.6124	0.0002
V2*Q1	-0.028761	7.6853	0.0056
V2*R1	0.011733	7.7189	0.0055
V2*R2	-0.003301	3.5395	0.0599
Q1*Q1	-0.026727	7.2397	0.0071
Q1*R1	-0.003301	0.03224	0.8575
Q1*R2	-0.026727	3.248	0.0715

statistics exceed 0.04 for the regressions of the squared residuals indicates that the incidence of heteroskedasticity is very slight. Thus, the failure to correct the variance-covariance matrix should have only a small effect on the simulation.

4.4 Technical Efficiency and Parameter Estimates

Chi-square tests of individual parameter estimates indicate that the first-order parameter for the *de jure* headship variable (G1) is highly significant in the equations for both local maize with fertilizer and hybrid maize without fertilizer. The negative sign of the parameters indicates that *de jure* female-headed households in these cases are less technically efficient than households under other headship gender categories. This includes both male-headed households, the comparison groups, and *de facto* female-headed households, who are not shown to be less technically efficient than their male-headed counterparts. Thus, headship is found to influence technical efficiency in two of four technology regimes.

Because the production functions are estimated using the translog form, parameters are interpreted in two ways. Parameter estimates for binary variables are combined with means of the regressors to determine their impacts on predicted maize yields (Table 4.5). The equation to determine the percentage change in yields is expressed as

Table 4.5
Percent Change in Yields Associated with Binary Variables

Maize Variety	Nitrogen Application	De Jure FHH (G1)	De Facto FHH (G2)	Education (M1)	Manure Applied (M2)	Extension Training (M3)	Plot Weeded (M4)	Credit (M5)	Oxen Used to Plow Plot (M6)	Northern Region (R1)	Central Region (R2)
Hybrid Maize	Fertilizer	-18%	7%	2%	-14%	7%	-7%	20%	9%	8%	22%
	No Fertilizer	-14%	9%	17%	-7%	27%	-20%	51%	23%	15%	32%
Local Maize	Fertilizer	-2%	7%	2%	-4%	9%	-16%	20%	-14%	-8%	15%
	No Fertilizer	-6%	8%	11%	-4%	12%	-12%	46%	8%	2%	12%

Table 4.6
Output Elasticities for Fertilizer, Labor, and Land

Maize Variety	Nitrogen Application	Elasticity of Fertilizer	Elasticity of Labor	Elasticity of Land
Hybrid Maize	Fertilizer	0.10	-0.02	0.11
	No Fertilizer	...	-0.02	0.21
Local Maize	Fertilizer	0.08	-0.05	-0.01
	No Fertilizer	...	-0.01	0.00

$$(4.1) \quad \textit{percent change in yields} = \frac{\hat{\bar{y}}\Big|_{g_i, m_c = 1} - \hat{\bar{y}}\Big|_{g_i, m_d = 0}}{\hat{\bar{y}}\Big|_{g_i, m_d = 0}}.$$

Coefficients for continuous variables are interpreted using output elasticities (Table 4.6). In examining the influence of each dummy variable on production, the model consistently predicts decreased yields for female-headed households. Maize yields are up to 18 percent lower under in households under *de jure* female headship than in households under male headship, with significant second-order coefficients occurring in three of the four production functions. In the function for hybrid varieties grown without fertilizer, second-order variables denoting *de jure* female headship are reduced from the regression. However, the first-order variable is highly significant and manifests a 14 percent drop in kilograms of maize achieved per hectare compared to households under male headship. Estimated coefficients for variables indicating *de facto* headship are not found to be significant, but cause predicted yields to be between 7 and 9 percent higher than those in male-headed households for each function.

Parameter estimates for the first- and second-order parameters of education (M1) variables are not significant in regressions of maize production with fertilizer. Predicted yields for fertilizer users rise only 2 percent when the household head has received attended school. However, for unfertilized maize, education has a larger impact. Second-order education variables have been reduced from the equation for unfertilized hybrid

maize, but the first-order parameter estimate is highly significant and causes a 17 percent increase in predicted yields. Multiple second-order coefficients for education variables are significant for local maize grown without fertilizer. Here, education boosts predicted yields by 11 percent.

The variable indicating manure application (M2) has four or more highly significant parameter estimates in each regression. It is also correlated with decreases in predicted yields ranging from 4 to 14 percent for all technology regimes. The same is true of parameters for the variable indicating weeding (M4), which is associated with up to 20 percent drops in predicted yields. Decreases in yields associated with activities that make more nutrients available for cultivated crops suggest that weeding and manure applications could be strategies used most often by farmers with poor soil. Engaging in these activities may indicate that farmers are struggling to combat low fertility on severely depleted or marginal land.

Extension training (M3) and credit (M5) generate large increases in predicted yields for maize of both varieties. The most dramatic improvements resulting from extension and credit occur for hybrid maize grown without fertilizer. Yields on these plots increase an estimated 27 percent when the household head has had any extension contact and 51 percent when credit is used to purchase seeds, fertilizers, or pesticides. For all four techniques, the frequency of parameter estimates for these variables with very low p-values suggest that credit and extension are, in fact, effective vehicles to increase agricultural productivity.

Variables denoting households located in the North (R1) and Central (R2) regions show that households in the South generally have lower maize yields. Both variables have multiple highly significant parameter estimates in each production function. The regional disparity is expected, as land in the South is more densely populated and intensively cultivated than the northern and central areas of Malawi.

Output elasticities demonstrate the expected result that fertilizer, labor, and land is more productive in plots with hybrid maize than with local varieties. Land is slightly more productive in where hybrid plots are grown. A 1 percent increase in plot size produces an 0.11 percent increase in yields where fertilizer is used and a 0.21 percent increase when no fertilizer is used on hybrid crops. Fertilizer nitrogen also has a 25 percent larger elasticity for hybrid maize than for local varieties. The elasticity of labor is negative for all technology combinations, but is lowest for local maize grown with fertilizer (-0.05).

4.5 Determining the Nature of the Production Functions

4.5.1 Testing Second-Order Conditions

Before testing for profit maximization, it is important to determine whether the production functions are concave, satisfying the second-order condition for profit maximization. For this to occur, the Hessian matrix[15] for each function must be negative semi-definite. The determinants of the first and second principal Hessian minors for the

[15] The Hessian matrix is defined in Appendix 4.

Table 4.7

Test of Second-Order Conditions for Profit-Maximization

Maize Variety	Nitrogen Application	Determinant of H_1*	Determinant of H_2	Indication
Hybrid Maize	Fertilizer	0.3582	-0.0006	Concavity
	No Fertilizer	0.0002	...	Convexity
Local Maize	Fertilizer	0.0726	-0.00001	Concavity
	No Fertilizer	-0.0001	...	Concavity

*H1 and H2 denote the first-and second principal minors of the Hessian matrix evaluated at the mean.
For functions that exclude fertilizer use, there is only one variable input and only one determinant to consider.

Table 4.8
Mean Average and Marginal Products for Smallholders Cultivating Maize

Maize Variety	Nitrogen Application	Gender Category	Labor		Fertilizer	
			Average Product	Marginal Product	Average Product	Marginal Product
Hybrid Maize	Fertilizer	MHH	3.07	-0.32	67.57	3.58
		De Facto	3.25	-0.38	58.92	5.82
		De Jure	2.25	-0.07	37.85	3.89
	No Fertilizer	MHH	2.55	-0.14	...	...
		De Facto	3.66	-0.25	...	...
		De Jure	1.94	-0.12	...	...
Local Maize	Fertilizer	MHH	1.96	-0.07	44.89	2.67
		De Facto	2.06	-0.06	45.44	4.25
		De Jure	1.60	0.08	49.30	0.54
	No Fertilizer	MHH	1.58	0.01	...	...
		De Facto	1.94	-0.01	...	...
		De Jure	1.23	0.04	...	...

production functions of fertilizer users are of alternating sign (Table 4.7), satisfying the second-order condition for a local maximum. The function for local maize without fertilizer is also concave, as the determinant of the Hessian matrix for it is negative. However, the function for hybrid maize without fertilizer is not concave and thus can not be interpreted as a well-behaved production function to determine a point of profit-maximization.

4.5.2 Determining the Stage of Production

For the well-behaved production functions, it is important to determine whether the predicted marginal products are greater than or less than average product. In the event that farmers are not using an input at the profit-maximizing level, a marginal product that exceeds the input's average product reveals that producers are operating in Stage 1 of production and using too little of the resource. If marginal product is less than average product, the producers who fail to profit-maximize are operating in Stage 2 or Stage 3 of production, where marginal product is decreasing, and are using too much of the resource.

Average product exceeds marginal product for labor and fertilizer in all three production functions across headship gender categories (Table 4.8), indicating that farmers as a whole are operating in Stage 2. The stage of production can not be ascertained for farmers growing hybrid maize without fertilizer because this maize production function is not well-behaved. The marginal product of labor for this function

is tested to see if it is similar to the actual input-output price ratio in Section 4.6, but can not be interpreted further.

4.6 Testing for Nonzero Shadow Prices

A profit-maximizing producer uses an unconstrained factor input at the level where its marginal product equals the ratio of the cost of an additional unit of the input to the output price (see Equation 3.2). A nonzero shadow price indicates a wedge between the marginal product of the input and the input-output price ratio (see Equation 3.3). To determine if the actual input-output price ratio is similar to the predicted input-output price ratio for each maize production regression, a simulation is performed on Equation 3.6.

$$(6)\quad \frac{w_h}{p_y} = \frac{y_t}{v_h}\Big(\hat{\alpha}_h + \tfrac{1}{2}\sum_{b=1}^{2}\hat{\vartheta}_{bh} g_{it} + \tfrac{1}{2}\sum_{d=1}^{6}\hat{\nu}_{dh} m_{dt} + \sum_{i=1}^{2}\hat{\tau}_{hi}\ln v_{it} + \tfrac{1}{2}\hat{\upsilon}_h \ln z_t + \tfrac{1}{2}\hat{\varphi}_h \ln e_t\Big) + \varpi_t,$$

One hundred random draws of the parameter vector are created using the variance-covariance matrix of the parameter estimates. Data are sorted by headship category into three subsets. The observations from each of these subsets then are substituted into each draw of the parameter vector to generate a distribution of the model's predicted input-output price ratio separately by headship gender. The distributions are compared with the actual input-output price ratios, reported by the NSSA SDA module and the World Bank

Africa Technical Department (Donovan, 1994),[16] to test if the observed ratios fall within a 95 percent confidence interval of their respective distributions.

Results of the test reveal that the hypothesis of profit maximization with respect to fertilizer nitrogen can not be rejected for farmers cultivating hybrid or local maize (Table 4.7). The actual nitrogen-to-maize price ratio for 1992-93, 2.77, falls within a 95 percent confidence interval of the predicted marginal product of fertilizer nitrogen for all headship groups of fertilizer users growing hybrid and local varieties. The mean predicted marginal product of fertilizer for male-headed households growing local maize, 2.76, is almost identical to the actual price ratio. However, the mean predicted marginal product for all hybrid growers, as well as for *de facto* female-headed households growing local maize, exceed the observed nitrogen-maize price ratio. Although the hypothesis of profit maximization can not be rejected for these farmers, the higher mean predicted marginal products indicate that on average these farmers may use less fertilizer nitrogen than would be optimal. Alternatively, *de jure* female-headed households have mean predicted fertilizer productivity that falls short of the observed price ratio in Stage 2 production, suggesting that they may often apply more fertilizer than would be optimal. This could occur because *de jure* female-headed households, who tend to be poorer than households under other categories of headship gender, are more risk averse. They may choose to use resources to purchase extra fertilizer for their local maize varieties rather than adopt higher yielding hybrid seeds.

[16] Please see Appendix 5 for the explicit calculation of input-output price ratios and the sources of each price.

Table 4.9

Predicted Intervals for the Marginal Product of Fertilizer

Maize Variety	Gender Category	Distribution*			Actual Price Ratio
		Lower	Mean	Upper	
Hybrid Maize	MHH	-12.14	3.66	29.00	2.77
	De Facto FHH	-5.25	5.78	42.05	
	De Jure FHH	-5.67	3.63	28.05	
Local Maize	MHH	-5.24	2.76	16.68	2.77
	De Facto FHH	-3.25	3.91	21.00	
	De Jure FHH	-18.55	0.36	13.18	

* "Lower" and "upper" represent the boundaries of the 95% confidence interval for the distribution of predicted marginal product.

Table 4.10

Predicted Intervals for the Labor-Maize Price Ratio

Maize Variety	Nitrogen Application	Gender Category	Distribution*			Actual Price Ratio
			Lower	Mean	Upper	
Hybrid Maize	Fertilizer	MHH	-1.05	-0.10	-0.33	6.95
		De Facto FHH	-1.45	-0.13	0.34	
		De Jure FHH	-0.60	-0.02	0.37	
	No Fertilizer	MHH	-1.24	-0.14	0.32	6.95
		De Facto FHH	-1.97	-0.25	0.47	
		De Jure FHH	-0.93	-0.12	0.18	
Local Maize	Fertilizer	MHH	-0.66	-0.07	0.52	6.95
		De Facto FHH	-0.63	-0.06	0.55	
		De Jure FHH	-0.21	0.08	0.69	
	No Fertilizer	MHH	-0.22	0.01	0.36	6.95
		De Facto FHH	-0.30	-0.01	0.36	
		De Jure FHH	-0.09	0.04	0.36	

* "Lower" and "upper" represent the boundaries of the 95% confidence interval for the distribution of predicted marginal product.

Profit maximization with respect to labor is rejected for all groups of smallholders, regardless of cultivation technique or headship gender (Table 4.10). The mean marginal product of labor is close to zero or slightly negative for local maize plots, and the confidence intervals fall well below the observed labor-maize price ratio of 6.95. The extremely low marginal product occurring in Stage 2 of production on local maize plots, as determined in Section 4.5.1, indicates that too much labor is available for household production on these farms. One reason for this outcome is that a lack of off-farm employment could result in more labor being reported as available in the household than is necessary to farm the cultivated area of the holding, depressing the estimated labor productivity.

Another explanation is that malnutrition, which is prevalent among the rural poor, is depressing actual labor productivity. Behrman (1993) presents evidence "that calories are fairly important in cross-farm variations in agricultural productivity" (p. 1754) in a review of the effects of malnutrition on the productivity of labor. The poorest *de jure* female-headed households, those growing local maize, have the highest predicted mean marginal productivity of labor of all local maize growers. The consistently increased labor productivity in these households suggests that nutrition may be a factor affecting the productivity estimates. Kennedy and Peters (1992) note that children in Malawi's *de jure* female-headed households score better in nutrition screenings than children from better-off male-headed and *de facto* female-headed households. They assert that *de jure* female household heads invest in their children's health to combat labor shortages,

thereby increasing their productivity. It is also possible that more labor being devoted to household production than is optimal is a reflection of risk aversion on the part of smallholders growing local maize. Local maize is generally grown as a subsistence crop (Gladwin, 1992) and devoting extra labor to subsistence production may be a means of insuring food security in smallholder households.

The extremely low marginal products of labor predicted for hybrid maize growers who use fertilizer are not likely to be explained by malnutrition because these households represent the wealthiest segment of the smallholder sector. Nor is it explained by a possible lack of employment opportunities, as hybrid maize growers often hire extra labor to cultivate their fields. It is more likely that the observations for available labor are overestimated for these households. This could happen because members of these households are more sure of their food security and cash flow due to higher maize yields and larger holdings. Thus, they may find it more profitable or desirable to hire labor instead of working through the entire agricultural year. They may have sent their children to school, as they are the group most able to afford the fees imposed in Malawi's primary schools until 1994. Households growing either hybrid or local maize may even have declined to report all of the time spent in off-farm employment, fearing that survey enumerators had some connection with government tax or debt collectors. Because the survey followed a year of massive debt default and took place in the midst of high

tensions associated with Malawi's first democratic election, this is a reasonable supposition.[17]

4.7 Constraints vs. Allocative Inefficiency

Nonzero shadow prices observed for fertilizer users and local maize growers who do not use fertilizer could be due to either allocative inefficiency or the existence of a resource constraint. A constraint would arise if only a limited amount of a factor input is available for purchase, if a producer is unable to acquire funds to purchase the input, or if an input is not divisible into quantities small enough to apply at profit-maximizing levels. Alternatively, allocative inefficiency is the failure of a producer to use factor inputs in optimal proportions and quantities, where the value of the marginal product of each input equals its price. (Kumbakhar, 1994; Pudasaini, 1983). If divergences from optimal ratios were due to allocative inefficiencies, then the variables in the regression models that might influence a smallholder farmer's ability to obtain and apply market information to allocate inputs in a profit-maximizing manner are education and extension training. Equation 3.6 is simulated a second time to determine if these factors influence the nonzero shadow prices, implying that allocative inefficiency rather than resource constraints may be preventing profit-maximization. Data subsets are sorted according to gender, education, and extension training variables.

[17] As explained in Section 4.5.1, the marginal product of labor for hybrid maize plots without fertilizer can not be interpreted because the function is not well-behaved.

Table 4.11
Changes in Mean Predicted Marginal Product Associated with the Education and Extension Training of Household Heads

Gender Category	Cultivation Technique	Change in Mean Marginal Product of Labor with	
		Education	Extension
MHH	Hybrid with Fertilizer	-0.08	0.07
	Hybrid with No Fertilizer	-0.18	0.06
	Local with Fertilizer	0.01	0.06
	Local with No Fertilizer	-0.06	0.01
De Facto FHH	Hybrid with Fertilizer	0.04	0.22
	Hybrid with No Fertilizer	-0.01	0.18
	Local with Fertilizer	0.00	0.01
	Local with No Fertilizer	-0.07	-0.03
De Jure FHH	Hybrid with Fertilizer	-0.03	0.13
	Hybrid with No Fertilizer	-0.10	-0.02
	Local with Fertilizer	0.00	0.12
	Local with No Fertilizer	-0.05	0.01

The results of this second series of simulations show that neither education nor extension has a large or consistent impact on the predicted mean marginal product of labor (Table 4.9). Extension training is associated with consistently positive shifts toward the actual input-output price ratio for all households using fertilizer, regardless of headship gender. However, it has no large effect on the marginal product of labor for any other group of farmers. It also does not increase the predicted marginal product enough that the labor-maize price ratio falls within the distribution for those particular groups of farmers. No consistent increases in the mean predicted the marginal product of labor are associated with education for any headship category or technology regime. Like extension, it does not cause any changes in tests for profit-maximization. Thus, it can be concluded that input constraints rather than allocative inefficiency cause the observed divergences from profit-maximization for all headship gender categories.

4.8 Summary of Results

In conclusion, it is determined that *de jure* female headship has an adverse effect on production. *De jure* female-headed households are less technically efficient and have lower predicted yields than male-headed and *de facto* female-headed households. However, no evidence of gender-specific constraints on fertilizer or labor is discovered. Smallholders are found to maximize profits with respect to fertilizer under all categories of headship gender. Resource constraints are shown to exist causing surplus labor across all technology regimes and headship gender groups. Thus, although *de jure* female-

headed households are shown to have lower levels of technical efficiency and predicted yields, there is no evidence that they face unique input constraints revealed in the results.[18]

[18] Please see Appendix 6 for model results using the Cobb-Douglas functional form in the regressions.

Chapter 5

Implications and Future Research

5.1 Does Gender Matter? Profit-Maximization and Input Constraints

This study estimates smallholder production functions and tests for profit-maximization with the intention of uncovering unique input constraints facing female-headed households. The results, described in Chapter 4, indicate that deviation from profit-maximizing input use does not depend on headship gender. Smallholders who use fertilizer consistently profit-maximize with respect to fertilizer nitrogen on hybrid and local plots. Further, they use labor on all plots in quantities exceeding the optimal level where marginal product equals the input-output price ratio, regardless of the technology regime or the gender of the household head.

Differential technical efficiency is evident, as *de jure* female-headed households growing local maize with fertilizer and growing hybrid maize without fertilizer are found to be less technically efficient than their peers. However, gender-differentiated allocative inefficiency is not evident. In no instance does the inclusion of education or extension training allow any headship gender category using any cultivation technique to satisfy the test for profit-maximization where it otherwise would not. Therefore, the model results imply the existence of sizable and pervasive constraints on the use of fertilizer and labor for all households.

5.2 Observations on Efficiency in the Smallholder Sector

According to the NSSA, fertilizer users constitute less than one-third of smallholder farmers. The fertilizer-maize ratio in Malawi is one of the highest in the world (Sahn et al., 1990). Such relatively high prices for fertilizer may make it unprofitable for smallholders cultivating the most severely depleted or marginal land to adopt this technology because poor soil quality suppresses marginal productivity. Recently, large devaluations in the Malawi Kwacha have counteracted the effects of expanded competition in lowering fertilizer prices. Thus, it would be worthwhile to examine opportunities to produce fertilizer domestically. If rock- nitrates and phosphates are expensive to import, organic fertilizers are a good option.

Organic fertilizers may be well suited to the needs of Malawian farmers, as intensive cropping has left soil in many regions depleted and in need of organic-matter, as well as nutrient, supplements. (World Bank, 1994) Land where hybrid seeds have been adopted is much more productive than land planted with local varieties (Table 5.1), suggesting that soil quality may be a key issue in adoption decisions. Where local maize is grown, land productivity is very low or negative. Therefore, by improving overall soil quality, the use of organic fertilizers may encourage the adoption of hybrid seeds in addition to widening access to fertilizer. Organically based fertilizers are also less likely to fall prey to leaching and runoff problems during the heavy downpours of Malawi's rainy season.

Table 5.1
Mean Marginal Products for Smallholders Cultivating Maize

Maize Variety	Nitrogen Application	Gender Category	Marginal Product of Land
Hybrid Maize	Fertilizer	MHH	5970.76
		De Facto	704.30
		De Jure	954.47
	No Fertilizer	MHH	906.23
		De Facto	858.52
		De Jure	625.30
Local Maize	Fertilizer	MHH	-6.86
		De Facto	58.65
		De Jure	-375.61
	No Fertilizer	MHH	-147.33
		De Facto	-400.90
		De Jure	-8.21

Model results indicate that it is imperative to develop opportunities for off-farm employment. The extremely low marginal product of labor for households growing local maize, the majority of whom do not hire field help, clearly shows there is "excess" labor available on these farms. Off-farm employment is important in rural areas for several reasons. First, food processing and light manufacturing industries producing for export could become an important source of foreign exchange, acting to diminish debilitating foreign exchange shortages and act as a hedge against drops in world tobacco prices. Second, off-farm employment could provide a means for the poorest households to supplement their incomes, helping to alleviate poverty. Further, wages earned would serve as a reliable source of cash to allow farmers with the smallest land holdings to purchase fertilizer and hybrid seeds or to qualify for credit to purchase them. The cash flow and organization of small-scale enterprise could even act as a catalyst for the development of rural financial institutions-- results show that credit availability increases agricultural productivity. In a country with severe and growing land scarcity, there must be an alternative to agriculture for earning a living in rural areas.

A fear of food shortages may also compel the use of extra labor as a security measure in household maize production. Smallholders may fail the test for profit maximization because that is not their main objective. The quest for self-sufficiency in maize production possibly acts as a constraint compelling excessive use of labor in maize cultivation. Because the majority of smallholders produce in maize-deficit households, this phenomenon could have a detrimental effect on overall agricultural productivity in

the Malawian economy, channeling labor resources away from more productive entrepreneurial activities. ADMARC policies throughout the 1970s and 1980s encouraged farmers to be self-sufficient in maize production by suppressing producer prices. Although structural adjustment programs have discouraged ADMARC's price-distorting activities since the mid-1980s, households that purchased maize in 1993 could expect to pay almost double ADMARC's offering price for producers.

The recent liberalization in maize marketing is an important step in reconnecting consumer prices with producer costs, but at the moment it is incomplete due to high transactions costs. Trading during the 1992-93 agricultural year was restricted by licensing requirements[19] and a poorly managed state-owned transportation conglomerate. Following liberalization of maize markets under structural adjustment, the high costs of transport have been passed on by private traders in the form of higher prices for smallholders. In some areas, transport shortages prevent any market access at all for small farmers because transport is so costly due to infrastructure deficiencies and remaining informal restrictions to trading. Reducing transactions costs by increasing access to transport is imperative to continue the development of Malawi's grain markets. Coupled with price liberalization, increased access will allow post-harvest prices to reflect production and storage costs. Better-functioning markets will raise smallholders' confidence that if they do not store enough grain from their own fields for household consumption they will not be able to purchase food in the market later in the season.

[19] These restrictions have since been removed.

5.3 Why Gender Might Still Be an Important Variable

The results of the study indicate that there is little difference in the production environment for male and female household heads. However, there are several key areas where gender potentially could make a difference in yields that data limitations preclude detecting with these regression models. The first are "hidden" constraints: differential soil nutrient, cash, labor, and social resources. The existence of "hidden" constraints is obvious because of the under-representation of *de jure* female household heads among hybrid maize growers and fertilizer users. The production function does not encompass factors such as off-farm cash income, the lack of which may prevent many women from purchasing hybrid seeds and fertilizer or from obtaining seasonal credit necessary to purchase these inputs. The results for farmers using fertilizer indicate that once a woman overcomes a cash or credit constraint, she allocates fertilizer as well, or poorly, as her male peers.

Another factor the models do not encompass is poor soil quality. This model does not contain a variable representing soil type or nutrient content. It is possible that this effects the analysis in two ways. First, it may reduce the accuracy of the measurement of the marginal product of fertilizer by allowing excessive unexplained variance in yield responses to fertilizer nitrogen. Therefore, higher marginal products achieved due to more fertile soil are not clearly apparent because this variable is missing. Underestimation of the yield response to fertilizer could effect the outcomes of the

gender-specific tests for profit-maximization because it is likely that female-headed households farm land of poorer quality than males. Just as women with small landholdings often have difficulty finding husbands or have husbands who migrate in search of wage labor to supplement household income, women possessing cultivation rights to land of marginal quality may also have a greater chance of becoming household heads. Poor soil quality could both reduce yields, inviting poverty and malnutrition into a higher proportion of female-headed households, and make fertilizer applications less profitable, as marginal land may require additional applications to yield harvests comparable to more fertile holdings.

There are also some important vagaries in the data used for fertilizer and labor variables that could bring gender-neutral fertilizer- and labor- response rates expressed in the regressions into question. First, some farmers may have confused the survey question, "How many bags of fertilizer did you use on this plot?" with "How many bags of fertilizer did you use altogether?" Smallholders surveyed may not have the same idea of the boundaries of a "plot" as the surveyor and answered in reference to a larger area of land, possibly inflating fertilizer usage estimates. As the survey took place in the midst of an election campaign, many farmers were skeptical that the surveyors were agents of the government. They may have reported applying subsidized fertilizer on their own maize crops when actually it was sold to nearby estates or applied to other crops out of fear of reprisal. All of these misunderstandings could be much more common between female household heads, who are not socialized to interact with strange men freely, and

NSSA enumerators, who are presumably all males. Hence, misunderstanding between enumerators and respondents could inflate fertilizer usage estimates, thereby underestimating estimates of the marginal product of fertilizer disproportionately for female-headed households.

The estimate of available labor as the labor input in the production functions also may be inadequate to capture the dynamics of work in female-headed households. It is calculated as the sum of available household labor and hired labor, minus all reported days of off-farm employment. The estimate could inadvertently encompass time spent on household chores, childcare, and processing harvested maize-- all of which would consume a higher proportion of household labor in a female-headed household, as males do not generally participate in such activities. In addition, women in matrilineal societies often spend time helping to work in the fields of female relatives, an obligation which male heads of household may not have. Thus, the labor variable may overestimate the amount of labor available in female-headed households, underestimating their labor productivity relative to male-headed households.

5.4 Opportunities for Further Research

The above limitations of the model used in this study present some intriguing opportunities for research to better ascertain factors limiting agricultural productivity and input use in female-headed households. One approach would be to simply add soil-quality variables at the EA level and a more localized measure of rainfall to the current

model.[20] These additions could make yield response estimates to fertilizer and labor variables in the estimated regressions more accurate, perhaps uncovering an undetected pattern of gender-differentiated input productivity or pinpointing poor soil quality as a deterrent to technology adoption.

A study investigating soil quality and headship gender would help determine whether poor land is a factor in the reluctance or inability of *de jure* female-headed households to apply fertilizer and adopt hybrid varieties. Research up to now has affirmed that female-headed households have smaller holdings, but has not discussed the possibility that the smaller size may compel them to deplete their soil through intensive cultivation more severely than households headed by males, who are better able to supplement household production with off-farm wage earnings. It is also possible that as land grows more scarce and increasing areas of marginal land come under cultivation, women inheriting this land may not be able to attract husbands. Therefore, the number of households finding it unprofitable or impossible to purchase fertilizer or improved maize varieties due to infertile soil may be disproportionately female-headed. Poor land quality could be a key factor in the prevalence of what Hirschman (1992) calls "the feminization of poverty" in rural Malawi.

A more detailed, small-scale study of production at the household level would also be a useful development in the literature on Malawian female-headed households. Using the current model, but a more detailed survey, precise data on labor, fertilizer

[20] Adding soil quality and rainfall variables to survey forms in the next NSSA may facilitate more accurate studies of the smallholder sector in the future.

nitrogen, manure, extension support, and credit usage could be used to obtain more accurate results. If such an effort included villages in all three regions of the country, it would also be useful to examine how cultural practices help or hurt production in female-headed households. For instance, is there more of a stigma among the Moslem Tumbuka than among the matrilocal Chewa and Yao that discourages females from receiving extension training from male extension agents? Are children or relatives within certain cultures more apt to help with fieldwork or household duties when a female household head experiences labor shortages? Perhaps most important to the well-being of a female-headed household is the question of whether women in certain areas are discouraged from entrepreneurial endeavors more than others or if employers of certain cultural backgrounds are less likely to hire women and pay fair wages. Cultural practices and variations in cultural practices within Malawi are largely overlooked when examining economic reasons for the over-representation of women among Malawi's poor.

5.5 Contributions of This Study

The model presented here offers a contribution to the use of production economics as a first attempt to integrate the economic dynamics of gender into profit-maximization. The empirical analysis of the study is limited in terms of the precision of labor and environmental variables used and its homogeneous treatment of households from different cultural regions. However, it suggests a new method to examine different socioeconomic groups— here defined by headship gender— within the framework of

production theory and presents an example of an empirical application of the model. As an updated assessment of the condition of female-headed households in Malawi, this paper is also a useful addition to the literature on African women farmers, which is important to understanding issues of production and food security in the region.

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Appendix 1

Profit Maximization

The model pinpoints factor input constraints faced by smallholder farmers by testing for evidence of profit-maximizing management techniques within a Neoclassical framework. Neoclassical economic theory holds that a farmer will increase production until the cost of producing an extra unit equals the revenues to be gained by selling the extra unit. To produce less than this amount would leave potential profits unexploited. Producing more would actually incur losses to the farmer, as the costs of producing each extra unit would exceed the price it will attract on the market. This "marginal cost equals marginal revenue" rule theoretically holds in markets with many producers of the same product as long as the producers do not face limits on the amount of inputs they can use.

This rule also implies that, in the absence of such resource constraints, farmers will increase the amount of each input in the production process until the cost of an additional unit of the input equals the revenues to be gained from the additional production that results when all other input levels remain unchanged. The marginal cost of the input thus equals the marginal value of its product. However, if input use is constrained, so that only a limited amount of a factor can be used, the cost of a unit of the input will be less than the price of the additional product it would generate, leaving profits unexploited.

Mathematically, profit maximization stipulates that all first-order derivatives of the profit function equal zero (establishing the necessary condition of a critical point) and that all second-order derivatives are less than zero (establishing the sufficient condition of a maximum at the critical point). (Chiang, 1984) For a production function

$$y = f(x_i)$$

where y is the level of output produced in a process using inputs x_i, the profit function can be expressed as

$$\pi = p \cdot f(x_i) - w_i x_i$$

In this case, p is the market price of one unit of the output and w_i is the price of one unit of the ith input. If a producer maximizing profits, the first-order conditions of profit-maximization imply that first-order partial derivatives with respect to each input will equal zero:

$$\frac{\partial \pi}{\partial x_i} = 0$$

Alternatively,

$$p \cdot f'(x_i) = w_i$$

Thus, the price of an input will equal the output price times the additional output that an extra unit of the input will generate: the marginal cost will equal the value of the marginal product of each input. (Beattie and Taylor, 1993) This key result in Neoclassical theory is used to test for resource constraints in the following empirical analysis. Using a production function estimated from the NSSA data, as well as

supplemental input and output price data, the study determines which groups of households do not use certain inputs at profit maximizing levels, implying that they face constraints on the use of these resources.

Appendix 2

Health and Education

With a quickly growing population, the educational system is severely overtaxed. Due to the recent removal of primary school fees, enrollment has increased about 60 percent. Although the government has tripled its spending on education, giving special emphasis to primary education, the student/teacher ratio is a chaotic 131 and there is an average of 422 students for each classroom. The average Malawian receives only 1.7 years of schooling. Low levels of education are significant because the poorest households are more likely to be headed by individuals with little or no schooling; they are half as likely to have their children enrolled in school. Overall, the net enrollment rate for boys does not greatly exceed the rate for girls (World Bank, 1995). However, in the rural South, where an estimated 60 percent of poor households are headed by females (World Bank, 1995b), the enrollment rate for girls is 25 percent lower (World Bank, 1995). Males also stay in school twice as long as females (UNDP, 1994). Nationwide, 64 percent of females over the age of 15 have no primary school education (World Bank, 1991).

Like the educational system, the growing population also overwhelms the rural transport and healthcare infrastructure. Due to the high cost of fuel and spare parts, as well as a parastatal monopoly on passenger transport, 90 percent of all travel in rural areas is done on foot. Over half of Malawians have no access to safe drinking water and

44 percent must walk over 5 km to reach the nearest improved water source (Cromwell, 1992). The ratio of medical workers to the population has tripled since 1970 so that 80 percent of the population has access to health services. However, the ratio of doctors to citizens in Malawi remains substantially lower than the average for Sub-Saharan Africa, and two and a half times the average for developing countries as a whole. Despite population pressures, only 13 percent of married couples of childbearing age use contraceptives (UNDP, 1994). Another problem is the spread of AIDS, which is reaching epidemic proportions. By the year 2000, an estimated 2 million people will be HIV positive (World Bank, 1995b).

Appendix 3

Computer Resources

The data for the study from the Garden Survey, SDA module, and Household Composition module of the NSSA require approximately 64.75 MB of memory storage space. Distributions generated by the simulation using all observations in each technology subset and 100 perturbations of the parameter vectors requires approximately 300 MB of disk storage space, except for the local maize regression with no fertilizer use. The distribution generated for the predicted marginal product of labor using all observations requires 1 GB of storage space, in this case.

Before using the NSSA data for a Monte Carlo simulation, it is advisable to make sure that sufficient computer memory and processing capacity is available.

Appendix 4

Hessian Matrices

The first and second principal minor of the Hessian matrices for the maize production functions in this study are defined and evaluated for fertilizer users as follows:

$$|H_1| = \left| \frac{\partial^2 y}{\partial v_1^2} \right|$$

$$|H_2| = \begin{vmatrix} \frac{\partial^2 y}{\partial v_1^2} & \frac{\partial^2 y}{\partial v_1 \partial v_2} \\ \frac{\partial^2 y}{\partial v_1 \partial v_2} & \frac{\partial^2 y}{\partial v_2^2} \end{vmatrix}$$

Alternating signs indicate convexity and therefore a local maximum. For regressions that do not include fertilizer use, only one principal minor is evaluated. It is defined as

$$|H_1| = \left| \frac{\partial^2 \quad y}{\partial \quad v_2^{\ 2}} \right|$$

and a negative sign indicates convexity and a local maximum.

Appendix 5

Computation of Input-Output Price Ratios

Dr. Harold Taylor, economist for the United States Department of Agriculture, recommended the following process for calculating the price of fertilizer nitrogen: multiply the price per unit by the ratio of nitrogen to the total nutrient content of the fertilizer. The calculation is explicitly outlined in Table 3.1A using fertilizer price data from the World Bank AFTES Working Paper, "Malawi: Economic Reform and Agricultural Strategy," from which the prices for maize are also taken. Maize prices in 1992 and 1993 were 0.270 MK/kg and 0.297 MK/kg, respectively. Dividing the average price of nitrogen per kilogram— 0.5886MK in 1992 and 0.8223MK in 1993— by the price of maize, the fertilizer-maize price ratio was 2.1799 in 1992 and 2.7688 in 1993.

The national average of daily wages for informal (non-estate) agricultural labor is calculated from smallholder reports of wages received in the SDA module of the 1992-93 NSSA. It is 2.067 MK/day. It is consistent with earlier World Bank reports of *ganyu* wage levels (World Bank, 1991).

Table 4.1A
Calculation of the Price of Fertilizer Nitrogen per Kilogram

Fertilizer Type	Nitrogen Content	Ratio of Nitrogen to Total Nutrient Content	Fertilizer Price 1992 (MK/kg)	Fertilizer Price 1993 (MK/kg)	Price of Nitrogen 1992 (MK/kg)	Price of Nitrogen 1993 (MK/kg)
DAP	18%	0.2813	0.980	1.323	0.2756	0.3721
Urea	46%	1.0000	0.900	1.216	0.9000	1.2160
23:21:0+4S	23%	0.4792	1.000	1.400	0.4792	0.6708
Sulfate of Ammonia	21%	0.4667	0.960	0.996	0.4480	0.4648
CAN	27%	1.0000	0.840	1.388	0.8400	0.3880

Appendix 6

Results Using Cobb-Douglas Functional Form

Table 6.1A
Tests for Normality of the Residuals
Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Number of Observations	Skew	Probability >Chi-sq	Kurtosis	Probability >Chi-sq	K-Squared	Probability >Chi-sq
Hybrid Maize	Fertilizer	4943	-27.09	0.0000	11.97	0.0000	877.33	0.0000
	No Fertilizer	6119	-22.82	0.0000	4.92	0.0000	544.98	0.0000
Local Maize	Fertilizer	5077	-20.41	0.0000	6.83	0.0000	463.18	0.0000
	No Fertilizer	17127	-26.39	0.0000	-3.58	0.0003	709.39	0.0000

Table 6.2A
Results of RESET Test For Linearity
Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Adjusted R-Squared	F-Value	Probability >F
Hybrid Maize	Fertilizer	0.00	1.25	0.2295
	No Fertilizer	0.00	0.86	0.6017
Local Maize	Fertilizer	0.00	0.14	1.0000
	No Fertilizer	0.00	0.33	0.9902

Table 6.3A
Results of White's Test For Heteroskedasticity
Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Adjusted R-Squared	F-Value	Probability >F
Hybrid Maize	Fertilizer	0.01	5.76	0.0001
	No Fertilizer	0.01	6.59	0.0001
Local Maize	Fertilizer	0.02	7.44	0.0001
	No Fertilizer	0.01	7.95	0.0001

Table 6.4aA

Parameter Estimates and Model Regressors: Hybrid Maize with Fertilizer

Cobb-Douglas Functional Form *

	N=4943	Adjusted R2=0.06	
Regressor	**Parameter Estimate**	**Chi-sq Value**	**Probability >Chisq**
De_Jure FHH (G1)	-0.165942	32.14	0.0000
De_Facto FHH (G2)	-0.00929183	0.04	0.8540
Education of HH Head (M1)	-0.017717	0.50	0.4780
Manure Application (M2)	-0.096734	11.10	0.0009
Extension Training (M3)	-0.020244	0.31	1.0100
Weeding (M4)	0.088707	0.70	0.4034
Credit Used (M5)	0.120279	34.07	0.0000
Oxen Labor Used (M6)	-0.023403	0.66	0.1893
Monthly Rainfall-cm (E)	-0.022618	0.51	0.4762
Fertilizer Nitrogen-kg/ha (V1)	0.085704	54.36	0.0000
Labor-man days (V2)	-0.00714537	0.39	0.5300
Plot Size-ha (Q1)	0.078606	39.94	0.0000
Northern Region (R1)	0.174557	21.88	0.0000
Central Region (R2)	0.197915	75.14	0.0000

* The sum of the parameter estimates is 0.38, which is less than one. Thus, the function is concave.

Table 6.4bA

Parameter Estimates and Model Regressors: Local Maize with Fertilizer

Cobb-Douglas Functional Form

	N=5077	Adjusted R2=0.04	
Regressor	**Parameter Estimate**	**Chi-sq Value**	**Probability >Chisq**
De_Jure FHH (G1)	-0.00882621	0.13	0.7208
De_Facto FHH (G2)	0.021741	0.17	0.6825
Education of HH Head (M1)	0.024161	1.20	0.2738
Manure Application (M2)	-0.014881	0.51	0.4767
Extension Training (M3)	0.031107	2.23	0.1351
Weeding (M4)	0.0829	0.61	0.4360
Credit Used (M5)	0.135133	57.51	0.0000
Oxen Labor Used (M6)	-0.178594	5.34	0.0208
Monthly Rainfall-cm (E)	0.157275	28.05	0.0000
Fertilizer Nitrogen-kg/ha (V1)	0.058919	35.38	0.0000
Labor-man days (V2)	-0.011594	0.79	0.3727
Plot Size-ha (Q1)	-0.0013431	0.00	0.9886
Northern Region (R1)	0.058869	2.09	0.1478
Central Region (R2)	0.119511	34.94	0.0000

* The sum of the parameter estimates is 0.47, which is less than 1. Thus, the function is concave.

Table 6.4cA

Parameter Estimates and Model Regressors: Hybrid Maize with No Fertilize

Cobb-Douglas Functional Form *

	N=6110	Adjusted R2=0.11	
Regressor	**Parameter Estimate**	**Chi-sq Value**	**Probability >Chisq**
De_Jure FHH (G1)	-0.075633	10.40	0.0013
De_Facto FHH (G2)	-0.052397	1.17	0.2798
Education of HH Head (M1)	0.081503	14.46	0.0001
Manure Application (M2)	-0.0133	0.26	0.6124
Extension Training (M3)	0.082471	16.27	0.0001
Weeding (M4)	-0.099582	17.12	0.0000
Credit Used (M5)	0.307745	224.76	0.0000
Oxen Labor Used (M6)	0.051849	0.90	0.3435
Monthly Rainfall-cm (E)	-0.07974	9.16	0.0025
Labor-man days (V2)	-0.000735	0.00	0.9473
Plot Size-ha (Q1)	0.031588	10.27	0.0014
Northern Region (R1)	0.156134	21.61	0.0000
Central Region (R2)	0.177886	64.76	0.0000

* The sum of the parameter estimates is 0.57, which is less than 1. Thus, the function is concave.

Table 6.4dA

Parameter Estimates and Model Regressors: Local Maize with No Fertilizer

Cobb-Douglas Functional Form *

	N=17127	Adjusted R2=0.04	
Regressor	**Parameter Estimate**	**Chi-sq Value**	**Probability >Chisq**
De_Jure FHH (G1)	-0.025204	4.48	0.0344
De_Facto FHH (G2)	0.000742	0.00	0.9798
Education of HH Head (M1)	0.057186	20.83	0.0000
Manure Application (M2)	-0.001797	0.02	0.9023
Extension Training (M3)	0.053412	17.71	0.0000
Weeding (M4)	0.002443	0.02	0.8796
Credit Used (M5)	0.336801	297.16	0.0000
Oxen Labor Used (M6)	0.029459	0.79	0.3754
Monthly Rainfall-cm (E)	-0.160122	105.29	0.0000
Labor-man days (V2)	0.009615	1.91	0.1675
Plot Size-ha (Q1)	0.031671	25.76	0.0000
Northern Region (R1)	-0.009098	0.27	0.6001
Central Region (R2)	0.07074	37.63	0.0000

* The sum of the parameter estimates is 0.40, which is less than 1. Thus, the function is concave.

Table 6.5A
Output Elasticities for Fertilizer, Labor, and Land
Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Elasticity of Fertilizer	Elasticity of Labor	Elasticity of Land
Hybrid Maize	Fertilizer	0.09	-0.01	0.08
	No Fertilizer	...	0.00	0.03
Local Maize	Fertilizer	0.06	-0.01	0.00
	No Fertilizer	...	0.01	0.03

Table 6.6A
Mean Average and Marginal Products for Smallholders Cultivating Maize
Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Gender Category	Labor		Fertilizer	
			Average Product	Marginal Product	Average Product	Marginal Product
Hybrid Maize	Fertilizer	MHH	3.07	-0.02	67.62	5.80
		De Facto	3.25	-0.02	5.04	58.92
		De Jure	2.25	-0.02	37.85	3.24
	No Fertilizer	MHH	2.56	-0.01	...	...
		De Facto	3.66	-0.02	...	...
		De Jure	1.95	0.00	...	...
Local Maize	Fertilizer	MHH	1.95	-0.02	44.89	2.64
		De Facto	2.06	-0.02	45.44	2.68
		De Jure	1.60	-0.02	49.30	2.90
	No Fertilizer	MHH	1.58	0.01	...	...
		De Facto	1.94	0.01	...	...
		De Jure	1.23	0.01	...	...

Table 6.7A

Predicted Intervals for the Marginal Product of Fertilizer

Cobb-Douglas Functional Form

Maize Variety	Gender Category	Distribution*			Actual Price-Ratio
		Lower	Mean	Upper	
Hybrid Maize	MHH	0.22	5.84	22.17	2.77
	De Facto FHH	0.37	5.03	32.06	
	De Jure FHH	0.17	3.27	12.27	
Local Maize	MHH	0.13	2.57	12.93	2.77
	De Facto FHH	0.12	2.77	14.05	
	De Jure FHH	0.12	2.99	16.52	

* "Lower" and "Upper" represent the boundaries of the 95% confidence interval for the distribution of predicted marginal product

Table 6.8A

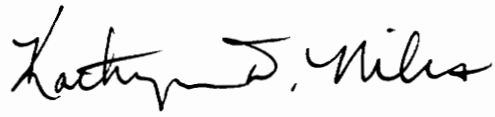
Predicted Intervals for the Labor-Maize Price Ratio

Cobb-Douglas Functional Form

Maize Variety	Nitrogen Application	Gender Category	Distribution*			Actual Price Ratio**
			2.5%	Mean	97.5%	
Hybrid Maize	Fertilizer	MHH	-0.19	-0.02	0.08	6.95
		De Facto FHH	-0.19	-0.02	0.08	
		De Jure FHH	-0.14	-0.02	0.05	
	No Fertilizer	MHH	-0.09	-0.01	0.05	6.95
		De Facto FHH	-0.14	-0.02	0.05	
		De Jure FHH	-0.05	0.00	0.06	
Local Maize	Fertilizer	MHH	-0.12	-0.02	0.02	6.95
		De Facto FHH	-0.12	-0.02	0.03	
		De Jure FHH	-0.10	-0.02	0.02	
	No Fertilizer	MHH	0.00	0.01	0.08	6.95
		De Facto FHH	-0.01	0.01	0.09	
		De Jure FHH	0.00	0.01	0.06	

* 2.5% and 97.5% represent the boundaries of the 95% confidence interval for the distribution of predicted marginal produ

** National average

VITA

Katheryn D. Niles was born in Schenectady, New York in January 1973. She grew up in Balcksburg, Virginia and received her Bachelor of Arts from the College of William and Mary in 1994. As an undergraduate, she also had the opportunity to work and study extensively in Tokyo and Kanazawa, Japan. She attended Virginia Tech for her Master's degree in Agricultural and Applied Economics. After graduation, Katheryn and her husband plan to spend the next few years serving as Peace Corps volunteers in Guatemala.