AGRICULTURAL EFFICIENCY AND DEPENDENCY ON FOREST RESOURCES:
AN ECONOMIC ANALYSIS OF RURAL HOUSEHOLDS AND THE
CONSERVATION OF NATURAL FORESTS IN SRI LANKA

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI'I IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

AGRICULTURAL AND RESOURCE ECONOMICS

DECEMBER 2006

By.

Prabodh M.P. Illukpitiya

Dissertation Committee:

John F. Yanagida, Chairperson
Kent D. Kobayashi
Samir A. El-Swaify
Gary R. Vieth
Richard Bowen
We certify that we have read this dissertation and that, in our opinion, it is satisfactory in scope and quality as a dissertation for the degree of Doctor of Philosophy in Agricultural and Resource Economics.

DISERTATION COMMITTEE

[Signatures]
Chairperson
Kent D. Kihagachi
Gary P. Vietti
Richard O'Brien
TO HONOR MY LOVING PARENTS
FOR THEIR ENDLESS LOVE, EVER PRESENT, DESPITE INFINITE DIFFICULTIES AFFECTING THEIR LIVES
ACKNOWLEDGEMENTS

In completing this dissertation I greatly acknowledge the assistance I received from numerous individuals and institutions. First, I would like to extend sincere thanks to my academic advisor, Dr. John F. Yanagida, who encouraged me to carry out this interesting dissertation research and for his invaluable advice, guidance, endless encouragement and untiring efforts to make it a success. He provided a stimulating environment with productive discussions throughout the dissertation research. I am grateful to him for his support and wisdom, and the kindhearted assistance extended to me throughout the study period. I am extremely thankful for helpful comments from my dissertation committee members Dr. Kent D. Kobayashi, Dr. Samir A. El-Swaify, Dr. Gary R. Vieith and Dr. Richard Bowen. I would also like to express my sincere thanks to Dr. Chennat Gopalakrishnan and Dr. Michael Robotham for their assistance.

I gratefully acknowledge the Asian Development Bank-Japanese Government scholarship program and the East West Center for providing financial support for my graduate studies. Particularly I would like to thank Mendl Djunaidy, Associate Dean at the East-West Center education program for her continuous assistance throughout my graduate studies. The International Development Research Center (IDRC) through the Environmental Economics Program for Southeast Asia (EEPSEA) in particular provided financial assistance for dissertation research. Particularly I am grateful to Dr. David Glover for his strong support for my research. My gratitude also goes to Dr. Nancy Olewiler, Simon Fraiser University, Canada for her constructive comments and suggestions especially during EEPSEA bi-annual workshops.
I am thankful to Dr. Silvia Yuen for providing me with a graduate assistantship to complete my studies. I also extend my special thank to Dr. P. Abeygunawardena, of the Asian Development Bank in Philippines who consistently supported my graduate studies.

Rural households in the forest sites in Badulla district deserve my thanks for their cooperation in the data gathering effort. I greatly appreciate the help given by many individuals during the data collection process. I am also grateful for the special friendship of my colleague, M.B. Ratnayake. I thank the Sabaragamuwa University of Sri Lanka for granting me study leave to pursue my postgraduate studies at the University of Hawaii at Manoa.

Appreciation goes to Judy Rantala for her enormous support especially during difficult period of our life in Hawaii. I must recognize the constant help given by my colleagues at the department, for their assistance and cooperation throughout the course of study.

I am indebted to my brother and sister who helped to encourage and inspire me at all times to successfully complete my studies at the University of Hawaii at Manoa. Special thanks to my wife Chandi for her understanding, patience and encouragement throughout my graduate studies. My sons Binula and Chirath were a constant source of love and pleasure during this period and they both have earned my thanks for that.

Finally, the highest recognition goes to my loving parents for their endless love, ever present, despite infinite difficulties affecting their lives. I dedicate this dissertation to them.
ABSTRACT

Households living in the peripheral villages of natural forests are primarily dependent on agriculture and secondarily dependent on forest gatherings. High rates of forest dependency occur, in part, from the efforts of inefficient farmers securing subsistence. Due to excessive use, the productivity of the remaining forests is at a critical stage. Technical efficiency of agriculture in forest peripheries is one aspect in which agricultural capacity and rural incomes can be enhanced. The study's main objective was to assess the technical efficiency of farming in forest margins and to determine how it affects dependency on forest resources by rural households.

The findings of the study show that the mean technical efficiency in agricultural farming in forest peripheries ranges between 0.67 - 0.73. Factors such as age, education, experience, extension, and the nutrition status of the household head are mainly responsible for determining the level of technical efficiency. Further, study findings suggest factors such as agricultural efficiency, off-farm income, wealth, and the diversification index had negative and significant effects on dependency of rural households on forest resource extraction. It is estimated that on average, an increase in mean efficiency by 0.1 would increase agricultural revenue by 2,142 - 3,987 rupees/farm. Based on the threshold efficiency levels needed to arrest forest dependency, it is estimated that increasing agricultural income through increasing technical efficiency can be partly compensated for forest resource extraction. Compared to the measured efficiency levels, the efficiency gap needs to be addressed by policy measures range from 2-14 percent for non-timber forest products categories and 10-26 percent for the
fuelwood category. Agricultural inefficiency can be minimized via policies to enhance farmer education, extension and nutrition status of households.

Income diversification and off-farm employment may be other viable options to minimize forest dependency. Based on the economic value of forest products extracted from each forest reserve, it is estimated that increasing efficiency by 0.1 would reduce the opportunity cost of biodiversity conservation by 27, 46, 34, and 75 percent respectively in the forest areas under investigation.

The study findings showed that intersectoral activities such as agriculture produce positive externalities in forest conservation. An efficiency improvement in rural agriculture can be partly compensated by higher opportunity costs of biodiversity conservation. Hence, improving agricultural efficiency in forest peripheries should be an integral part of forest conservation policy.

Improving efficiency and income diversification helps to alleviate poverty and reduce forest dependency. However, given the complex nature of protecting natural forests, other issues such as land rights, capacity and effectiveness of institutions (for rural credit, information dissemination, subsidies, marketing), development of rural infrastructure, etc. have to be part of an integrated policy goal to protect natural forests.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS .............................................................................................................. v

ABSTRACT ................................................................................................................................ vii

LIST OF TABLES ............................................................................................................................ xii

LIST OF FIGURES ......................................................................................................................... xiv

CHAPTER 1: INTRODUCTION .......................................................................................................... 1

1.1 The Case in Sri Lanka ........................................................................................................... 3

1.1.1 Recent Trends in Forest Policies in Sri Lanka ............................................................. 3

1.2 Problem Statement ............................................................................................................... 5

1.3 Aims and Objectives ............................................................................................................ 9

1.4 Expected Contributions of the Study ................................................................................... 10

1.5 Organization .......................................................................................................................... 11

CHAPTER 2: REVIEW OF ISSUES IN TROPICAL FORESTRY ............................................... 12

2.1 Deforestation and Forest Degradation ............................................................................. 12

2.2 Market Failures and Forest Degradation ......................................................................... 13

2.3 Households Consumption and Dependency of NTFPs .................................................. 16

2.4 Household Models in Tropical Forestry ........................................................................... 18

CHAPTER 3: THEORETICAL MODEL ...................................................................................... 22

3.1 Theoretical Model ............................................................................................................... 22

3.1.1 Comparative Static Analyses ....................................................................................... 27

3.1.1.1 Comparative Static 1 ............................................................................................. 27

3.1.1.2 Comparative Static 2 ............................................................................................. 29

3.1.2 Analysis of Phase Diagrams ....................................................................................... 31

3.1.2.2 Technical Efficiency in Agriculture ........................................................................ 33

3.1.3 Phase Diagram (Increase in Efficiency for Agriculture) ............................................. 34

CHAPTER 4: DATA INFORMATION ....................................................................................... 36

4.1 Approach ............................................................................................................................... 36

4.2 Sample ................................................................................................................................ 37

4.3 Survey Design ....................................................................................................................... 38

4.4 Data Sources ......................................................................................................................... 39
CHAPTER 5: ESTIMATION OF TECHNICAL EFFICIENCY .............................................. 42
  5.1 Theoretical Model (The Stochastic Frontier Model) ............................................. 42
  5.2 Empirical Model .................................................................................................... 46
  5.2.1 Results and Discussion ..................................................................................... 49
  5.3 Theoretical Model (Data Envelopment Analysis) ..................................................... 56
  5.3.1 Results and Discussion ..................................................................................... 58

CHAPTER 6: ESTIMATION OF FOREST DEPENDENCY ........................................... 60
  6.1 Theoretical Background .......................................................................................... 60
  6.2 Empirical Model .................................................................................................... 62
    6.2.1 Hypothetical Scenario Associated with the Forest Dependency Model .......... 63
    6.2.2 Probit Estimation ............................................................................................ 68
    6.2.3 Possible Problems Associated with the Empirical Model ............................... 70
  6.3 Results and Discussion ......................................................................................... 72
    6.3.1 Estimation of Forest Dependency Model (NTFP and Fuelwood) ................. 72
    6.3.2 Estimation of Forest Dependency Model (NTFP Only) ................................ 76
    6.3.3 Estimation of Forest Dependency Model (Fuelwood) .................................... 79
    6.3.4 Estimation of Forest Dependency Model (Probit Analysis) ......................... 83
    6.3.5 Economic Value of NTFP and Fuelwood to Rural Communities ................ 84
    6.3.6 Potential Benefits from Increasing Technical Efficiency ............................. 86

CHAPTER 7: SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS .......... 90
  7.1 Summary ................................................................................................................ 90
  7.2 Conclusions ........................................................................................................... 92
  7.3 Limitations of the Study ....................................................................................... 93
  7.4. Policy Options ..................................................................................................... 94

APPENDIX A: FOREST TYPES MAP OF BADULLA DISTRICT ......................... 104
APPENDIX B: LAND USE DATA IN BADULLA DISTRICT ................................. 105
APPENDIX C: DETERMINISTIC FRONTIER MODEL ......................................... 106
APPENDIX D: SUMMARY STATISTICS ................................................................. 109
APPENDIX E: RESULTS OF CHOW TEST .............................................................. 110
APPENDIX F: VARIABILITY AMONG HOUSEHOLD ............................................ 111
APPENDIX G: RESULTS OF DEA ANALYSIS ....................................................... 112
APPENDIX H: HETEROSKEDASTICITY TEST RESULTS ................................. 113
APPENDIX I: FOREST DEPENDENCY AS AN INCOME RATIO ....................... 114
APPENDIX J: TECHNICAL EFFICIENCY VS FOREST INCOME ......................... 117
APPENDIX K: TECHNICAL EFFICIENCY VS AGRICULTURE INCOME .......... 122
APPENDIX L: TECHNICAL EFFICIENCY VS TOTAL INCOME .................... 127
APPENDIX M: DIVERSIFICATION AND FOREST INCOME ....................... 128
APPENDIX N: INCOME DIVERSIFICATION VS TOTAL INCOME ............... 133
APPENDIX O: MARGINAL EFFECTS OF PROBIT ESTIMATION .................. 134
REFERENCES ........................................................................................................ 135
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1. Changes in factors of production and the shadow price of land.</td>
<td>20</td>
</tr>
<tr>
<td>5.1. ML estimates for the Dunhinda and Kithulanahela forest reserves.</td>
<td>53</td>
</tr>
<tr>
<td>5.2. ML estimates for the Galagodabedda and Bibilehela-Welanvita forest reserves</td>
<td>54</td>
</tr>
<tr>
<td>5.3. Technical efficiency ranges in agricultural farms in forest peripherics</td>
<td>55</td>
</tr>
<tr>
<td>5.4. Mean efficiency scores in DEA model.</td>
<td>58</td>
</tr>
<tr>
<td>5.5. Return to scale in DEA analysis.</td>
<td>59</td>
</tr>
<tr>
<td>6.1. Theoretical relationships between exogenous and endogenous variables</td>
<td>62</td>
</tr>
<tr>
<td>6.2. Estimation on forest dependency for all forest product category</td>
<td>75</td>
</tr>
<tr>
<td>6.3. Estimation on forest dependency for the NTFP only</td>
<td>78</td>
</tr>
<tr>
<td>6.4. Estimation on forest dependency for the fuelwood.</td>
<td>82</td>
</tr>
<tr>
<td>6.5. Probit estimation of the determinants of forest dependency</td>
<td>84</td>
</tr>
<tr>
<td>6.6. Economic value of NTFPs and fuelwood to households.</td>
<td>86</td>
</tr>
<tr>
<td>6.7. Projected threshold efficiency levels needed to arrest forest dependency</td>
<td>88</td>
</tr>
<tr>
<td>6.8. Estimated reduction of opportunity cost of biodiversity conservation</td>
<td>89</td>
</tr>
<tr>
<td>B.1. Land use patterns in the divisional secretaries of Badulla district</td>
<td>105</td>
</tr>
<tr>
<td>D.1. Summary statistics of key variables.</td>
<td>109</td>
</tr>
<tr>
<td>E.1. Comparison of regression coefficients (Chow Test).</td>
<td>110</td>
</tr>
<tr>
<td>F.1. Coefficient of variation in key variables.</td>
<td>111</td>
</tr>
<tr>
<td>G.1. Technical efficiency ranges in DEA analysis.</td>
<td>112</td>
</tr>
<tr>
<td>H.1. Heteroskedasticity tests results for original model.</td>
<td>113</td>
</tr>
</tbody>
</table>
H.2. Heteroskedasticity tests results for corrected model. ................................. 113

1.1. Estimation on forest dependency as an income ratio for all forest products ......... 114
1.2. Estimation on forest dependency as an income ratio for NTFPs category .......... 115
1.3. Estimation on forest dependency as an income ratio for fuelwood category ....... 116

O.1. Probit estimation on marginal effects on determinants of forest dependency .... 134
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1. Effect of technical efficiency in agriculture on equilibrium forest resource stock</td>
<td>35</td>
</tr>
<tr>
<td>5.1. Stochastic frontier production function</td>
<td>44</td>
</tr>
<tr>
<td>A.1. Badulla district forest map</td>
<td>104</td>
</tr>
<tr>
<td>J.1. Technical efficiency vs forest income for Dunhinda forest reserve</td>
<td>117</td>
</tr>
<tr>
<td>J.2. Technical efficiency vs forest income for Kithulahela forest reserve</td>
<td>118</td>
</tr>
<tr>
<td>J.3. Technical efficiency vs forest income for Galagodabedda forest reserve</td>
<td>119</td>
</tr>
<tr>
<td>J.4. Technical efficiency vs forest income for Bibilehela-Welanvita forest reserve</td>
<td>120</td>
</tr>
<tr>
<td>J.5. Technical efficiency vs forest income for all forest reserves</td>
<td>121</td>
</tr>
<tr>
<td>K.1. Technical efficiency vs agriculture income for Dunhinda forest reserve</td>
<td>122</td>
</tr>
<tr>
<td>K.2. Technical efficiency vs agriculture income for Kithulahela forest reserve</td>
<td>123</td>
</tr>
<tr>
<td>K.3. Technical efficiency vs agriculture income for Galagodabedda forest reserve</td>
<td>124</td>
</tr>
<tr>
<td>K.4. Technical efficiency vs agriculture income for Bibilehela-Welanvita forest reserve</td>
<td>125</td>
</tr>
<tr>
<td>K.5. Technical efficiency vs agriculture income for all forest reserve</td>
<td>126</td>
</tr>
<tr>
<td>L.1. Relationship between technical efficiency and household total income</td>
<td>127</td>
</tr>
<tr>
<td>M.1. Diversification vs forest income for Dunhinda forest reserve</td>
<td>128</td>
</tr>
<tr>
<td>M.2. Diversification vs forest income for Kithulahela forest reserve</td>
<td>129</td>
</tr>
<tr>
<td>M.3. Diversification vs forest income for Galagodabedda forest reserve</td>
<td>130</td>
</tr>
<tr>
<td>M.4. Diversification vs forest income for Bibilehela-Welanvita forest reserve</td>
<td>131</td>
</tr>
<tr>
<td>M.5. Diversification vs forest income for all forest reserves</td>
<td>132</td>
</tr>
<tr>
<td>N.1. Relationship between income diversification and household total income</td>
<td>133</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Over the past few decades, environmental and developmental concerns have converged, with increasing interest in both tropical forests as an important ecosystem, and in the well-being of people who live near them. At the same time, tropical forests are subject to high rates of degradation and deforestation, with current estimates indicating a loss of some 17 million ha, or more than 1 percent of the total forest area, per year (Byron and Arnold, 1999). Without a doubt, protection is one of the methods of assuring the continuation of tropical forests (see Hyde, 1980 for alternative ways of conserving natural forests). A primary factor acknowledged as a constraint to the successful establishment of protected areas in tropical countries is the lack of clear linkages between the well-being of local residents and conservation efforts undertaken in protected areas. Local residents are dependent on protected areas for a variety of reasons. Very often conservation efforts conflict with local subsistence demands, which erodes any protective measures undertaken (Shyamsundar and Kramer, 1996).

The concept of forest dependency is focused on the degree of concentration of a particular forest based livelihood in a particular area. Given this concern, analysts often proceed by identifying dependent communities that exceed a given, arbitrarily imposed, dependency threshold. For example, Vedeld et al., (2004) measured forest dependency as forestry income’s share of total income which often declines with increasing total income when analyzing across households. Bahuguna (2000) estimated forest dependency as a percentage of income derived from forest products of households. Accordingly, forest dependency varies from 37-76 percent in the investigated villages of Madhya Pradesh,
Orissa and Gujarat in India (also, see Cook and Mizer (1994) and Ross and Green (1985), for definitions for farming and recreational dependency).

Some scholars assume that the extraction of plants and animals from the forest by rural populations helps conservation because foraging does not disturb the forest as much as logging. However, leaving aside the injudicious extraction of forest goods by recent harvesters, there are evidences that even indigenous people far from markets can deplete forest goods (Godoy and Bawa, 1993). As the evidence of Paleo-Indian hunters in North America shows (Martin, 1984), population growth or technological change can lead people to deplete natural resources. Extraction may be a viable activity only in areas with low population densities (Homma, 1992).

A fundamental problem for conservation and development programs lies in the lack of knowledge about factors that influence choices between traditional activities made by forest households. To make matters worse, recent work shows that the resource use behavior of the households is, in fact, quite diverse both within and across communities (Browder, 1992; Coomes, 1996; Coomes and Barham, 1997). This diversity or heterogeneity means that whereas non-timber forest products (NTFPs) represent major sources of income for some households, others in the same community may rely primarily on agriculture for their livelihood. Moreover, major shifts within families over time suggest that changes in household specialization or reliance are quite common. Thus, what factors influence household participation in NTFP extraction activities becomes a relevant question.
1.1 The Case in Sri Lanka

In Sri Lanka, there is a long tradition of forest product use by communities living in close proximity to forests, either as an economic mainstay or as a supplementary source of household income. Forests are important as an economic buffer and safety net for poor households. Exploitation of wild species, the enrichment of natural forests with economically important species and the adoption of complex agro forestry systems are all examples of a close relationship between people and forests in Sri Lanka (Wickramasinghe et al., 1996).

As the natural forest cover in Sri Lanka has gone down to a critical stage and to arrest further degradation, various steps have been taken to conserve forest resources. These measures are embedded especially in the recent forest policies in the country.

1.1.1 Recent Trends in Forest Policies in Sri Lanka

Sri Lanka’s forest policies have changed in order to reflect a new era after the 1980’s. Due to rapid deforestation and forest degradation, the need for a comprehensive forest development plan arose. This led to the development of the Forestry Master Plan (FMP) during the 1983-1986 period. Major deficiencies of the FMP were the failure to address environmental aspects of forestry and failing to involve key players in the planning process (UNDP, 2004). Taking into account the new challenges of Sri Lanka’s forest sector, the National Forest Policy (NFP) was formulated in 1995. The major objectives of the NFP were to:

1. conserve forests for posterity with particular regard to biodiversity, soils, water and historical, religious and aesthetic values,
2. increase tree cover and productivity of the forests to meet the needs of present and future generations in terms of available forest products and services, and

3. enhance the contribution of forestry to the welfare of the rural population and strengthen the national economy with special attention paid to equity in economic development.

The Forestry Sector Master Plan (FSMP) was prepared based on the concepts of conservation, community participation and the new economic policies of the government (FPU, 1995). The FSMP upholds the spirit of the NFP by providing a sector development framework for 1995-2020. The reorientation accomplished through the NFP led the forest department to develop the 1997 Five-Year Implementation Program (FYIP). The FYIP prescribes a balance between conservation and sustainable forest management supported by public and private sector smallholder participation in commercial forestry, and provided a sectoral implementation framework as suggested in the FSMP.

Drawn-up plans for the FYIP included forestland allocation and macro-level planning, multiple-use management, commercial forest plantations, social forestry/agroforestry development, wood-based industry management and institutional strengthening.

Mainly, due to a delay in implementation, FYIP was updated and renamed the Seven-Year Implementation Plan (SYIP) in 2000 with assistance from the Asian Development Bank (ADB). The SYIP stresses the need to demarcate zone forestlands as a prerequisite to programs dealing with forest resources management, biodiversity conservation, conservation of soil and water resources, forest plantations, social and agroforestry development, and wood-based industries. According to ADB (2000),
government and the ADB have agreed on the following actions to facilitate implementation of the NFP:

a. deregulation of permits for transport of timber grown by the private sector,

b. private sector participation in harvesting, establishment, and management of state-owned plantations,

c. granting of 25-year leases or management rights to forestlands, with secure tenure arrangements for participating stakeholders, and delegation of power to the conservator of forests to issue such leases,

d. reorganization of the Department of Forest Conservation in Sri Lanka to establish and practice sustainable forest management, and

e. minimizing intersectoral incursions that undermine the long-term sustainability of national forests.

These forest policies have contributed significantly to conserving natural forests in Sri Lanka. However, many issues still exist including forest resource extraction by rural communities.

1.2 Problem Statement

Non-timber forest products are used by rural communities as energy sources, food items, medicinal products, materials for household equipments, construction materials etc. Several studies have documented the extent and product use particularly in the humid forests of Knuckles, Adams peak wilderness, Sinharaja, Ritigala and few wet zone forest patches in Sri Lanka (see for instance; Gunatilake et al., 1993; McDermott et al., 1990; Wickramasinghe et al., 1996; Bogahawatta, 1998). Continuous growth of population in rural areas along with low income generated from major income sources such as
agriculture have caused excess pressure on natural resources. Due to excessive use, the productivity of the natural forests is at a critical stage. In order to arrest the continuing problem of excessive extraction of NTFPs that leads to forest degradation, the government of Sri Lanka launched a number of conservation projects such as the Knuckles conservation program, Sinharaja conservation program, etc. These new policies were introduced specifically for the conservation of forests by limiting the consumption of NTFPs, banning logging activities in forests and reducing the conversion of forestlands to agriculture. This intervention acknowledges the severity of the forest dependency problem in Sri Lanka. However, most of the national forestry policies introduced in the past tend to reflect concerns, aspirations, and professional views of the relevant institutions, thus leaving the communities far removed from the decision making process. In most cases, the communities were not consulted to express their interests, concerns and ideas. Therefore, attempts to conserve forests have been ineffective due to lack of participation.

The problems that arise from conflicts between conservation and development require four-pronged solutions. First, make additional resources available to encourage human economic activities that do not pose a threat to the survival of essential forests. Second, encourage agricultural activities that are economically productive and at the same time, environmentally and ecologically sound. Third, careful planning is needed to conserve forests in order to achieve environmental and ecological objectives while utilizing forest products within viable limits. Last, reforest land to extend forest cover. Among these proposed solutions, this research will focus on improving agricultural
activities engaged by rural households thereby minimizing their dependency on forest resources, which will strengthen conservation of the natural forests in Sri Lanka.

Households living in peripheral villages of the protected forests are primarily dependent on agriculture and secondarily dependent on forest gatherings. High rates of forest dependency are driven, in part, by the effort of inefficient farmers to secure subsistence. Agricultural efficiency in forest peripheries is one aspect in which agricultural capacity and rural incomes can be enhanced. However, from an environmental perspective, attempts to raise rural incomes through agricultural improvement can result in an ambiguous effect (Shively, 2001). Technologies that increase the returns to agriculture can reduce the need for subsistence-driven land clearing. As Walker (2005) pointed out, in some situations arborization of agriculture could be justified to enhance the livelihood of upland farmers. However, raising incomes and returns to agricultural activities may also provide incentives to convert forestland to farmland or other uses (see Faris, 1999; Mattos and Uhl 1994; Nickerson, 1999; Theil and Wiebelt, 1994; Barbier and Burgess, 1996). According to these studies, deforestation is assumed to be an increasing function of agricultural yield. However, this assumption may not be applicable to countries where forest cover has already declined to a critical level (Repetto and Gillis, 1998) and where protected forests have been well demarcated with buffer zones and laws restricting conversion of forestlands to agriculture. Given that many Sri Lankan natural forests are legally protected from encroachment and conversion to agriculture, forest dependency by rural households in peripheral villages in protected forests will be a decreasing function of agricultural efficiency.
In view of the growing competition in the agricultural sector and high production costs, technical efficiency will become an important determinant in the future of rural farming. Developing and adopting new production technology can improve technical efficiency. In addition, farming can maintain its economic viability by improving the efficiency of existing operations with a given technology. In other words, total farm output can be increased without increasing total cost by making better use of available inputs and technology. Hence, technical efficiency decreases cost and *ceteris paribus* increases profit from farming. This would enable poor farmers to improve their standard of living.

Increasing technical efficiency in agriculture may have a decreasing effect on forest dependency in two ways namely: income effect and labor supply effect (see Tachibana et al., 1998 and Shively, 2001). An increase in agricultural profitability may arrest forest dependency due to a large income effect. The higher profit from farming, due to increasing technical efficiency, will be an incentive for rural households to be more engaged in farming activities. Technical efficiency in agriculture makes rural households wealthier due to increase profit from farming. As shown by Godoy and Bawa (1993), wealthier households are less interested in extraction of forest resources hence their dependency will decline. From the rural labor market point of view, increased farm activities imply greater involvement of household labor in farming hence decreasing the labor allocated to forest extraction. When farming becomes more profitable, the opportunity cost of participating in extraction activities increase.
This reasoning suggests that agricultural productivity in peripheral villages of natural forests negatively impacts forest resource dependency by local people. This action will also enhance the biological stock of forest resources.

If economic analysis determines that forest dependency is a decreasing function of technical efficiency in agriculture, and the efficiency improvement in agriculture increases farming income, this additional income compensates for income lost from reduced forest resource extraction activities. On economic grounds, this analytical reasoning will provide a basis for policy intervention to reduce forest dependency. Hence, finding ways to increase technical efficiency of agriculture and rural income without jeopardizing the remaining forest resources will be an important policy goal to protect forests while enhancing living conditions of neighboring communities.

1.3. Aims and Objectives

The major objective of this research is to determine how technical efficiency of farms located in forest peripheries alters dependency on forest resources. Hence, the major hypothesis tested in this study is that forest dependency is a negative function of technical efficiency of agriculture in forest peripheries.

The more specific objectives are to:

1. determine technical efficiency of farming activities in forest peripheries,

2. identify factors affecting the productivity and efficiency of farming in forest peripheries,

3. estimate the economic value of forest products extracted and the contribution of NTFPs to the rural economy,
4. identify various socio-economic factors including technical efficiency of agriculture which may influence forest dependency, and
5. determine the level of efficiency improvement needed to compensate for current income generated by NTFPs.

1.4 Expected Contributions of the Study

This research provides an in depth investigation of technical efficiency of agriculture in forest peripheries and its effect on rural household dependency on forest resources. Technical efficiency is an important factor in determining the future of farming by households in forest peripheries. There is very little or no information on technical efficiency of agriculture in forest peripheries. Information generated by this study will be useful for households in routine decision making, for example, optimal input combinations in farming and the allocation of household labor to farm and non-farm activities. In addition, this information will assist governmental and non-governmental agencies in designing extension programs and policies designed to assist farmers. Efficiency information can also assist banks and other credit agencies in evaluating loan applications from agricultural producers.

Low profitability in agriculture may cause negative impacts on the survival of natural forests. Farmers can increase output by making better use of available inputs and by adopting improved technology. This study attempts to measure the technical efficiency of farming in forest peripheries to determine the relationship between technical efficiency of agriculture and dependency on forest resources by rural households. The efficiency analysis will also help to identify sources where improvements can be made by examining the determinants of inefficiency. Further, the study assesses the monetary
benefits to farmers by improving technical efficiency and the contribution of NTFPs to the rural economy. This information will assist in identifying specific policy measures needed to improve technical efficiency of agriculture in order to compensate current monetary benefits gained by extracting forest goods. Hence, the study will provide vital information to improve the agricultural sector in forest peripheries and conserve the natural forests by minimizing household dependency on forest resources.

1.5 Organization

The remainder of the dissertation is organized into seven chapters. Chapter two reviews the literature related to tropical forestry. More specifically, this chapter examines the causes and solutions to forest degradation and issues related to household models in tropical forestry. The theoretical model is discussed in chapter three. Chapter four examines the data collection methodology, proposed survey and data sources. Chapter five examines any analyzes the translog frontier production function results. Analysis of forest dependency models are discussed in chapter six. Chapter seven concludes the research and provides policy implications.
CHAPTER 2
REVIEW OF ISSUES IN TROPICAL FORESTRY

Tropical forests are threatened by harvesting of timber species as well as NTFPs. Compared to timber harvesting, NTFPs are considered a low impact forest use compatible with forest conservation. Although potentially beneficial for rural households in the short term, continuous extraction of NTFPs further degrades forest resources (De Beer and McDermott, 1989; Ros-Tonen, 1999). Products, which can be harvested without killing the individual plant or animal and are abundant or can regenerate easily offer good prospects for sustainable management. Though deforestation and forest degradation seem like two different issues, Schreckenberg (2000) pointed out that for management of tropical forests, the distinction between NTFP and timber is rather artificial since there are many interrelated services derived from forests. Therefore, the issues regarding deforestation and forest degradation are discussed in this chapter. The more specific literature related to the analysis of this study is highlighted in sections 5.1 and 6.1.

2.1 Deforestation and Forest Degradation

Tropical forests are the most species rich ecosystems in the world, (Hartshorn, 1992). The number of species worldwide is unknown, but it is believed that globally, tropical forests contain about 50-90 percent (Miller et al., 1993) of the world's estimated 5-10 million species on just 7 percent of the earth's surface (Pearce and Brown, 1994; Southgate, 1994; Mahar, 1989). For example, in the Amazon rain forest there are over 2,000 known fish species compared to 250 species in the Mississippi river system and the 200 species found in all Europe (Mahar, 1989). The destruction of the rain forest affects
populations of these species. Many of the species, which have been lost in the past, have not been identified. Their inherent nature and aesthetic value along with potential agricultural and pharmaceutical values vanish with them (National Academy Press, 1992).

Deforestation presents a crisis of many dimensions involving international, national, and local concerns (Caviglia and Kahn, 2001). At the international level, there is great concern about the total amount of depleted forest (Anderson, 1990). Another international concern is that large-scale removals may bring about reductions of biodiversity (Baer, 1995; Pearce and Brown, 1994; National Academy Press, 1992; Anderson, 1990; Mahar, 1989). Deforestation, however, affects the local people, in particular local farm families, because in many cases it is their land that is destroyed in the process. For example, the tropical forest margins have been settled by many small farm families and ranchers. The families who depend upon the forest for their livelihood therefore, feel the impacts of deforestation (Caviglia and Kahn, 2001).

2.2 Market Failures and Forest Degradation

Forest degradation is the result of various market and government failures. These market and government failures account for human and social pressures and the social and economic problems, which exist today. These circumstances which have led to deforestation in the tropics are the result of poorly defined property rights for land ownership, ill conceived government policies that unfairly secure advantages to some farmers and ranchers through subsidies, and the divergence of social and private costs and benefits resulting from assigning different values to the forest.
Market failures occurring at the global, national, and local levels make it difficult to find an optimal solution to deforestation on all levels simultaneously. The optimal rate of deforestation is determined as the level of deforestation where the social and private benefits of the standing forest are equal. On each level, market forces are not securing the economically correct balance of land conversion and land conservation (Pearce and Brown, 1994). This situation occurs because, as with all public goods, those who convert or destroy the forest are not required to compensate those who value the standing forest.

The economic solution does not result in zero deforestation, but rather an economic balance of conversion and conservation, resulting in the optimal rate of deforestation. Simultaneously solving for the optimal rate of deforestation on all of these levels is not possible since benefits differ across communities. Kahn (1995) points out that deforestation rates, which are optimal from a national level perspective, may not be optimal from a global point of view because the country will only consider domestic costs and benefits and not take into account global non-use or existence benefits. International benefits of the tropical forest include non-use and existence values. National benefits may include timber for trade and the conversion of forests to plantations (i.e., tea, rubber, coffee) to support national trade balances and the national economy. At the local level, benefits of the forest include conversion to farms and ranches to support subsistence living.

Since an optimal solution can’t be found to help reduce forest degradation, a second best solution that induces a change in behavior can result in both an increase in the welfare on the local level as well as society. According to Caviglia and Khan, 2001, in Brazil, the rate of deforestation can be decreased in some regions by altering
traditional farming techniques and using sustainable agricultural practices. The indigenous people of the forest areas have used sustainable agricultural practices successfully for centuries (Kahn, 1995). Therefore, this practice is supported by many professionals as a sustainable technique and a promising alternative to slash-and-burn agriculture, although it is not a cure all for the forest degradation problem.

Traditional economic solutions to market failures are the allocation of property rights, taxing the source of the market failure, subsidizing correct behavior, use of tradable permits, and creating markets by the government, which induce proper market incentives. These solutions can’t be expected to yield an optimal solution (one where the marginal costs and benefits are equated) because of the complexity of the situation. Each of these solutions, individually, may only address a portion of the problem. For example, when property rights became more defined, the rate of deforestation in the Amazon did not decrease (Caviglia and Kahn, 2001). In addition, in the state of Rondônia, Brazil, farmers are continuing to burn their lots as they gain titles with no apparent concern for the future. Taxing and/or the use of marketable permits are not feasible in this area of the world since the economy is not well developed and farmers are very poor (Caviglia, 1998).

Local market failures can be resolved by altering the agricultural techniques of the majority of farmers. It is possible that farmers will adopt new methods of agriculture, which result in less environmental damage, if the private cost of the new or alternative method of agriculture decreased. As the private cost of alternative methods of agriculture (e.g., sustainable agriculture) decreases, the relative price of slash-and-burn agriculture
will increase. The market failure can, therefore be internalized as the relative benefits of
the standing forest increase at the local level.

2.3 Households Consumption and Dependency of NTFPs

Ethnobotanical studies have shown that livelihood of rural households living in
forest margins depend on a variety of forest products. Since the pioneering work by
Peters et al. (1989), various studies on NTFPs have taken place in different parts of the
world (a few examples include Falconer, 1990; Panayotou and Ashton, 1992; Godoy and
Bawa, 1993; Ruiz Perez and Byron, 1999; Cavendish, 2000; Godoy et al., 2000; Sheil
and Wunder, 2002; Vedeld et al., 2004). Income from forest products seldom appears to
account for a large share of a household’s total income, but is often important in filling
seasonal or other cash flow gaps, and coping with particular expenses or to respond to
unusual opportunities.

Based on the research findings by Ruiz-Pérez and Arnold (1996); Townson
(1995), and Wollenberg and Ingles (1998), Wollenberg and Belcher (2001) highlighted
that NTFPs play important subsistence and safety-net roles in the rural economy, but only
a small subset of forest products possesses potential for significant cash income and
employment generation. According to Wollenberg and Belcher (2001), the majority of
these products have low cash values and are used for consumption, rather than for sale.
Many are important, especially to the poorest households, because they are low cost, and
rarely have any alternatives. In contrast to these low value products, there is a smaller
number of NTFPs that can contribute significantly to rural cash incomes. However,
Marshall et al., (2003), identified 45 factors which significantly limit the
commercialization of NTFPs.
According to Wilkie et al., (2001), contribution of NTFPs to local and national economies is typically small relative to agriculture. The relatively small contribution of NTFPs to household economies is mirrored by the results of a recent review of global forest valuation studies (Costanza et al., 1997). Average worldwide values (converted to 1994 dollars with an additional correction for purchasing power) of tropical forests for food production, raw materials, and intangibles (i.e., carbon sequestration, biodiversity conservation, and ecological services) were $32, $315, and $1,660 per hectare per year respectively. Estimates of the direct (i.e., tangible) value of the forest may, however, be exaggerated given the short duration of most studies. According to Peters et al., (1989), the gross annual per hectare value of fruits and latex in the Amazon amounts to US$ 700. However according to Godoy et al., (2000) the combined value of consumption and sale of NTFPs to rural communities in Honduras were US $ 6-8 (18-24 per hectare). In India, Narendran et al., (2001) reported that mean annual per capita household income from NTFPs ranges from Rs. 134 – 4955 (US $ 3-100). Dominant NTFPs contribute 25-60% of household income. The various studies in other parts of the world have shown varying values (see Sheil and Wunder, 2002 for more discussion on this issue). In high productive forests, benefits from NTFPs exceed the returns from other less-sustainable alternative uses of forests. Returns from NTFPs in less productive forests have shown lower benefits when compared to alternative land uses.

Rural households harvesting and consumption decisions on forest products are influenced by market prices for forest products (see Kohlin, 1998 for detailed discussion). Several studies have shown that households are more price responsive to consumption decisions on forest goods (see Cooke, 1998; Mekonnen, 1998; Amacher, Hyde, and
Kanel (1998) for evidences). The income effect for the consumption of certain forest goods, such as fuelwood, has shown to be necessary goods for rural households. However, the effect of household income on the consumption of forest products is generally small, with some forest products being inferior goods in some economies.

Kohlin (1998) further highlighted the need to find evidence for substitution effect to evaluate the effectiveness of participatory forestry activities. Though Cooke (1998) and Mekonnen (1998) didn’t find evidence of the substitution effects, Amacher, Hyde and Joshee (1993) found evidence of substitution between forest goods. As most studies have focused only on a few NTFPs hence the understanding of price, income and substitution effects are limited.

2.4 Household Models in Tropical Forestry

A limited, but growing number of empirical studies examine the relationship between household characteristics and tropical deforestation. These models typically define the dependent variable as either the average rate or total amount of deforestation on a homestead. Common independent variables include: number of adult males (DeShazo, 1993), household size (Pichon and Bilsborrow, 1992), tenurial conditions (Southgate, 1990; Pichon and Bilsborrow 1992; Bedoya, 1987; Almeida, 1992; Lopez, 1993), assets at the time of settlement (Almeida, 1992), place of origin (Almeida, 1992), and accessibility to markets (Pichon and Bilsborrow, 1992; Southgate et al. 1991). Few studies have also included explicit economic variables such as crop prices, wage levels, other input prices, and income from various sources (Almeida, 1992; Lopez, 1993; Panayotou and Sungsuwan, 1992; Southgate, 1990). Noticeably absent from many of these studies is a theoretical framework (DeShazo and DeShazo, 1995). The absence of
such a framework has many consequences. First, when considering the relationship between dependent and independent variables, one cannot distinguish between correlation and causation. A second related issue is that without a theory of deforestation, one cannot properly formulate and evaluate empirical models of household behavior.

In addition, researchers include variables such as income that encompass countervailing effects on land clearing behavior without recognizing that the variable is not a proximate determinant of deforestation. Third, the methods employed in most of these studies assume that the estimated coefficients are temporarily invariant. Fourth, many studies ignore economic variables even though in the long run these factors almost certainly cause households to expand or contract land under cultivation. However, few models have examined the effect of household income on land clearing (Panayotou 1992; Tongpan et al., 1990).

The current set of empirical studies is suggestive but is either too macro in orientation or too oblique in specification to convincingly describe the household determinants of land clearing. A theory of settler deforestation can be abstracted from the complex relationships a household maintains with its economic and physical environment to provide intuition about the reasons why households clear additional land. In view of the need for conceptual and theoretical evidence, DeShazo and DeShazo (1995) described a simple two-stage framework of settlement that differentiates the determinants of deforestation (see Table 2.1 for the summary of the model).

According to this model, the household's incentive to convert forest to farmland is determined by the shadow value of an additional unit of farmland. If one assumes established property rights to all land, the shadow value of land would equal the cost of
buying the land. If private property rights are obtained for clearing the land, one could assume that agriculture will expand until all land rent is captured, except in the case where off-farm wage opportunities limit the availability of labor. Therefore, even if the shadow value of land is positive, a household may choose to expand, contract, or leave constant the land area under cultivation. Only if the shadow value of land is negative one can say with certainty that a household will not expand cultivation. Without knowledge of the cost of bringing another unit of land under cultivation, one cannot determine whether changes in the economic factors in Table 2.1 will cause additional land clearing.

Table 2.1. Changes in factors of production and the shadow price of land.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Effect on land rent</th>
<th>Shadow price of land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing output prices</td>
<td>$\frac{\partial \pi_i}{\partial p_i} &gt; 0$</td>
<td>Increases</td>
</tr>
<tr>
<td>Increasing input prices</td>
<td>$\frac{\partial \pi_i}{\partial v_i} &lt; 0$</td>
<td>Decreases</td>
</tr>
<tr>
<td>Increasing land cost</td>
<td>$\frac{\partial \pi_i}{\partial d_i} &lt; 0$</td>
<td>Decreases</td>
</tr>
<tr>
<td>Increasing labor prices</td>
<td>$\frac{\partial \pi_i}{\partial w_i} &lt; 0$</td>
<td>Decreases</td>
</tr>
<tr>
<td>Increasing yield per unit</td>
<td>$\frac{\partial \pi_i}{\partial z_i} &gt; 0$</td>
<td>Increases</td>
</tr>
</tbody>
</table>

$\pi_i$ is the shadow price of land

$p_i, v_i, d_i, w_i, z_i$ are the input price, land cost, labor cost and yield respectively.

An increase in the price of variable inputs, labor, or land; all cost factors in the production function will *ceteris paribus* lower the rents to land and, thus, reduce the shadow value of land. An increase in gross output prices, which could result from either an increase in the market price of or a decrease in the cost of transportation, will increase land rents by raising revenues relative to costs and thus, increasing profits. Therefore, the shadow value of land will increase.
Technological innovation may affect the shadow value of land in several ways. Technological innovation may increase the yield per unit of land or it may decrease the variable inputs or labor required per unit. In each case technological innovation increases rents to land. It may also simultaneously increase yields and increase input requirements per unit. Therefore, technological innovation may also result in higher prices for inputs, thus exacting a countervailing effect on land rents.

With these comparative statistics in hand, one can examine more critically the use of income as an explanatory variable in models of deforestation. However, because income is endogenous to local economic factors, it has ambiguous effects on land clearing depending on the source of the income (Deshazo and Deshazo, 1995). For example, using Table 2.1, compare a household’s response to an increase in income from an increase in the price of one of its outputs versus an increase in the market wage rate. If the price of a crop rises, increasing the shadow value of land, a household may choose to clear additional land to plant that crop. On the other hand, if the market wage rises, the opportunity cost of labor rises, causing rent to land to fall. In response, households may choose to allocate more of its labor to the market and reduce the amount of land under cultivation. In both cases, household income rises. However, in the first case, an increase in income leads to an increase in the shadow value of land and, perhaps, deforestation, while in the second case, an increase in income leads to a decrease in the shadow value of land and a reduction in the amount of land under cultivation.
CHAPTER 3
THEORETICAL MODEL

3.1. Theoretical Model

In order to fully understand how efficiency in agriculture influences the rate of forest extraction, it is necessary to build a conceptual link between agricultural production and forest dependency. Following the literature (i.e., Becker, 1965; Coomes and Barham, 1997; Gunatilake and Chakravorty, 2000; Pattanayak and Sills, 2001 and Tachibana et al., 2001), a dynamic model of the household was formed and presented below. The model incorporates all-important interrelationships used by Gunatilake and Chakravorty (2000), but focuses on elements that are central to its empirical structure.

In order to understand how agriculture influences forest dependency, arguments regarding labor allocation can be developed formally in order to highlight the mechanism that leads households to reallocate labor. Households are assumed to engage in three types of income generation activities, namely: agriculture, forest exploitation and off-farm work. Agriculture is identified by the subscript \((a)\), forest use is identified by the subscript \((f)\) and off-farm work is identified by the subscript \((o)\).

Agriculture production \(G(L_a)\) is a function of household labor allocated to agriculture \((L_a)\), purchased agricultural inputs \((I_a)\), household characteristics \((Z_p)\), area under cultivation \((A_a)\) and production efficiency \((E_a)\).

\[
G(L_a) = f(L_a, I_a, Z_p, A_a, E_a) \tag{3.1}
\]
Forest collection $F(L_f)$ is a function of household labor in forest collection ($L_f$), household characteristics ($Z_p$), forest access and quality ($F$), and accumulated forest knowledge ($K_f$). Because of the diversity and complexity of tropical forests, accumulated forest knowledge ($K_f$) affects the households' ability to collect forest product. Labor used in forest collection is one use of labor, which competes, with other uses including agricultural labor ($L_a$), off-farm wage labor ($L_o$), and leisure ($L_i$).

$$F(L_f) = f(L_f, Z_p, F, K_f)$$

$G(L_a)$ and $F(L_f)$ are assumed concave.

Total net income of the rural household living in the periphery of a protected tropical forest is given as:

$$\Pi = P_a(L_a, I_a, Z_p, A_a, E_a) - P_f I_a + P_f(L_f, Z_p, K_f, F) + W(L_o)$$

where:

$\Pi$ = total net income

$P_a$ = price of agricultural goods

$P_f$ = price of agricultural input

$P_f$ = price of forest products

$I_a$ = agricultural inputs

$W$ = off-farm wage rate

and $I_a + I_f + I_o + I_i = \bar{L}$ where: $\bar{L}$ = predetermined level of total labor input.

Formally, the representative household is assumed to maximize income subject to the change in forest stock $x_t$, and labor constraint ($\bar{L}$).
The standard growth function of a forest without harvesting is:

\[ \dot{X}_t = F(x_t, \gamma, K) \]  

\[ x_t > 0 \quad \text{and initial stock} \quad x_0 > 0 \]

Where:

\[ x_t = \text{resource stock of the forest} \]

\[ \gamma = \text{intrinsic growth (governed by the types of plant species, environmental conditions etc.)} \]

\[ K = \text{carrying capacity (if the forest reaches its carrying capacity then its growth approaches zero).} \]

The harvesting function can be represented as

\[ H_t = h(x_t, E_t) \]  

where \( E_t \) = effort level. As effort is governed by the labor allocated for forest extraction, \( H_t \) can be represented as:

\[ H_t = h(x_t, L_f) \]

Hence, the net growth function is:

\[ \dot{X}_t = F(x_t, \gamma, K) - h(x_t, L_f) \]

Harvest is an increasing function of both labor and the forest resource stock.

The representative household is assumed to solve the intertemporal maximization problem

\[ \max_{t, x_t} \left\{ \int_0^T U(\Pi) e^{-\rho t} dt \right\} \]

s.t. \[ \dot{X}_t = F(x_t, \gamma, K) - h(x_t, L_f) \]
where:

ρ is the discount rate

U is an instantaneous utility function assumed to be continuous, twice differentiable, non-decreasing and concave with \( U' > 0 \) and \( U'' < 0 \) which depend on household net income (Ω).

Leisure time is not an argument in the utility function since it is further assumed that any leisure time is predetermined at the beginning of each agricultural cycle (Bluffstone, 1995, Pascual and Barbier, 2001). The exclusion of leisure as a choice variable has some justification given that agricultural households are usually bound by a strict climatic calendar in each crop cycle, thus taking leisure time particularly as given for that whole agricultural cycle.

As shown by Chiang (1992), the current value Hamiltonian can be represented as:

\[
H_c = U(Ω) + \lambda \{F(x_t, γ, K) - h(x_t, L_f) \}
\]

\[
H_c = U[P_a G(L_a, I_a, Z_p, A_e, E_a) - P_i I_a + P_f f(L_f, Z_p, K_f, F) + WL_o] + \lambda \{F(x_t, γ, K) - h(x_t, L_f) \}
\]

λ is the co-state variable attached to the differential equation 3.7. The exogenous parameters are the \( P_a, P_f, P_i, A_e, E_a, γ, K, ρ \)

The first order necessary conditions with respect to \( I \) and \( L_f \) are:

\[
\frac{∂H_c}{∂I} = P_a G_I - P_i = 0
\]

\[
\frac{∂H_c}{∂L_f} = -P_a G_{L_a} + P_f f_{L_f} - \lambda h_{L_f} - W_{L_o} = 0
\]

(The first order conditions with respect to other endogenous parameters are not derived here to avoid the unnecessary complications of the model)
The first term in 3.11 comes from substituting the labor constraint into 3.9.

Time path of the state variable can be written as:

$$\frac{\partial H}{\partial \lambda} = \dot{X} = F(x_t, r_t, K) - h(x_t, L_f)$$  \hspace{1cm} (3.12)

Time path of the costate variable

$$\dot{\lambda}(t) = -\frac{\partial H_c}{\partial x_t} + \rho \lambda_t$$  \hspace{1cm} (3.13)

$$\dot{\lambda}(t) = \rho \lambda - \{P_j h_z + \lambda (F_x - h_z)\}$$

The transversality conditions are:

$$x(0) = x_0 \hspace{1cm} \lambda(T) \geq 0 \hspace{1cm} x(T) \geq 0 \hspace{1cm} \lambda(T) x(T) = 0$$

where $T$ is the time planning horizon and $T \rightarrow \infty$.

Equation 3.10 equates the marginal benefit of an incremental increase in purchased inputs to its marginal cost.

Equation 3.11 equates the marginal benefit of the labor input in forest extraction to its marginal cost. The forgone marginal benefit of not employing labor in farming $(-P_a G_{L_a})$, the opportunity cost of harvesting the forest resource today $(-\lambda h_{L_f})$ and forgone marginal benefit for not employing off-farm labor opportunities are the major components of 3.11.

Accordingly if $P_f f_{L_f} - \lambda h_{L_f} = P_a G_{L_a} + W_{L_a} > 0$, then the shadow price of the forest resource ($\lambda$) must be smaller than the price of the forest product. The net growth of the forest resource stock is given by equation 3.12. Rearranging the terms of 3.13 yields:

$$\rho \lambda - \dot{\lambda} + \lambda h_z = P_j h_z + \lambda F_x$$  \hspace{1cm} (3.14)
The right hand side indicates the benefit from harvesting the forest resources. The term \( P_f h_s \) is the direct benefits from harvesting while \( \lambda F_s \) represents benefits from the growth of forest resources.

### 3.1.1 Comparative Static Analyses

The following comparative static analyses can be developed following Caputo (1990). Equation 3.10 and 3.11 can be solved globally and uniquely using Gale and Nikaido (1995) as referred by Gunatilake and Chakravorty (2000) for \( L_f = \hat{L}_f(\lambda, \delta) \) and \( I_a = \hat{I}_a(\lambda, \delta) \) where:

\[
\delta = (P_a, P_f, P_i, W, E_a, A_a)
\]

\[
\begin{bmatrix}
\frac{\partial I}{\partial P_a} & \frac{\partial I}{\partial P_f} & \frac{\partial I}{\partial P_i} & \frac{\partial I}{\partial \omega} & \frac{\partial I}{\partial E_a} & \frac{\partial I}{\partial A_a} & \frac{\partial I}{\partial \lambda} \\
\frac{\partial L_f}{\partial P_a} & \frac{\partial L_f}{\partial P_f} & \frac{\partial L_f}{\partial P_i} & \frac{\partial L_f}{\partial \omega} & \frac{\partial L_f}{\partial E_a} & \frac{\partial L_f}{\partial A_a} & \frac{\partial L_f}{\partial \lambda} \\
\end{bmatrix}
\begin{bmatrix}
\frac{\partial F_1}{\partial \hat{L}_f} & \frac{\partial F_2}{\partial \hat{L}_f} \\
\frac{\partial F_1}{\partial \hat{I}_a} & \frac{\partial F_2}{\partial \hat{I}_a} \\
\end{bmatrix}
= \begin{bmatrix}
\frac{\partial F_1}{\partial \hat{I}_a} & \frac{\partial F_2}{\partial \hat{I}_a} \\
\frac{\partial F_1}{\partial \hat{L}_f} & \frac{\partial F_2}{\partial \hat{L}_f} \\
\end{bmatrix}
\]

\[
X = \begin{bmatrix}
G_{I_a} & 0 & -1 & 0 & P_a G_{I_a} & P_a G_{I_a} & 0 \\
-G_{I_a} & f_{L_f} & 0 & -1 & -P_a G_{I_a} & -P_a G_{I_a} & -h_{L_f}
\end{bmatrix}
\]

\[
Y = \begin{bmatrix}
P_a G_{I_a} \\
-P_a G_{I_a} + P_f f_{L_f} - \lambda h_{L_f}
\end{bmatrix}
\]

\[
|Y| = \begin{bmatrix}
P_a G_{I_a} G_{I_a} \left( G_{I_a} \right)^2 + P_a G_{I_a} \left( f_{L_f} - \lambda h_{L_f} \right) \end{bmatrix}
\]

\[
\frac{dL_f}{dE_a} = \frac{\left( P_a \right)^2 G_{I_a} G_{I_a} - \left( P_a \right)^2 G_{I_a} G_{I_a}}{|Y|} < 0
\]
Equation (3.17.1) implies that increased efficiency in agriculture leads to less labor allocated for forest extraction. This result is mainly due to the labor supply effect for other activities as a result of increasing efficiency in agriculture. As agricultural productivity is increasing, farming becomes a lucrative business, hence the opportunity cost of labor for forest resource extraction is high (see Tachibana et al., 2001 and Shively, 2001 for details). Farming in forest peripheries of Sri Lanka is a labor-intensive activity hence more labor is devoted to farming. Therefore, labor allocated for forest resource extraction may decline.

Similarly, expansion of the area under agriculture outside the protected forest will decrease labor use in forest resource gathering (3.17.2).

An increase in the price of agricultural products (3.17.3) leads to reduced labor allocated to extraction activities. This is due to the fact that higher agricultural product
prices are an incentive for households to allocate more labor to farming activities due to higher expected earnings. Similarly, higher prices of forest resources led to larger labor allocations for extraction activities (3.17.4).

Equation (3.17.5) suggests that the increase in agricultural input prices leads to larger allocation of labor for forest extraction. From equation (3.17.6), an increase in off-farm wage will decrease labor allocated for extraction activities.

Equation (3.17.7) indicates that the higher shadow price of the forest stock increases the opportunity cost of forest extraction hence decreases labor activities allocated to forest gathering.

3.1.1.2 Comparative Static 2

\[
\frac{dI_a}{dE_a} = -\frac{P_a G_{I_a} \left\{ P_a G_{I_a} + P_f f_{L_I L_f} - \lambda h_{I_a L_f} \right\} + (P_a)^2 G_{I_a} G_{I_a}}{|Y|} < 0 \quad 3.18.1
\]

\[
\frac{dI_a}{dA_a} = -\frac{P_a G_{I_a} \left\{ P_a G_{I_a} + P_f f_{L_I L_f} - \lambda h_{I_a L_f} \right\} + (P_a)^2 G_{I_a} G_{I_a}}{|Y|} > 0 \quad 3.18.2
\]

\[
\frac{dI_a}{dP_a} = -\frac{P_a G_{I_a} \left\{ P_a G_{I_a} + P_f f_{L_I L_f} - \lambda h_{I_a L_f} \right\} + (P_a)^2 G_{I_a} G_{I_a}}{|Y|} > 0 \quad 3.18.3
\]

\[
\frac{dI_a}{dP_f} = \frac{-P_a G_{I_a} f_{L_f}}{|Y|} < 0 \quad 3.18.4
\]

\[
\frac{dI_a}{dP_I} = \frac{P_a G_{I_a}}{|Y|} < 0 \quad 3.18.5
\]

\[
\frac{dI_a}{dW} = \frac{P_a G_{I_a}}{|Y|} < 0 \quad 3.18.6
\]

\[
\frac{dI_a}{d\lambda} = \frac{P_a G_{I_a} \lambda_{I_a}}{|Y|} > 0 \quad 3.18.7
\]
As shown in (3.18.1), the increase in agricultural efficiency implies production using less input. In other words, total farm output can be increased without increasing total cost by improving the use of available inputs and technology. Hence, agricultural efficiency decreases costs and *ceteris paribus* increases farmer profits. The result of a large income effect is households voluntarily deciding not to depend on forest gathering.

Equation (3.18.2) suggests that increases in farm area under cultivation leads to increases in purchased inputs.

Equation 3.18.3 indicates that increases in agricultural product prices leads to increases in agricultural input usage due to farming intensification. However, increases in the price of forest products is expected to decreases purchased inputs used in agriculture, as households substitute forest resource extraction for farming activities (3.18.4).

Equation (3.18.5) implies that increases in input prices will decrease the level of purchased inputs. Equation (3.18.6) suggests that increases in off-farm wages will decrease the use of purchased inputs, as households tend to focus less on agricultural activities.

The higher shadow price (3.18.7) of forest resources increases the opportunity cost of harvesting forest resources hence decreases extraction activities. This tends to increase the intensification of agriculture and use of agricultural inputs.

According to the above analysis, we could argue that increasing agricultural efficiency has a negative effect on forest dependency in two ways, an income effect and a labor supply effect. An increase in agricultural profitability may arrest forest dependency due to a potentially large income effect. Higher profits from farming due to increased efficiency are an incentive for rural households to be more engaged in farm production.
As farming becomes a profitable business, the opportunity cost of extraction activities increases and less time is allocated to forest resources extraction.

3.1.2 Analysis of Phase Diagrams

Referring to Gunatilake and Chakravorty (2000), comparative dynamics can be incorporated using perturbed phase diagram analysis. The procedure can be presented as follows:

Substitution of identities \( L_f = \hat{L}_f(\lambda, \delta) \) and \( I_a = \hat{I}(\lambda, \delta) \) into 3.12 and 3.13 leads to

\[
\dot{\lambda} = \rho \lambda - \{P_f h_2(x, \hat{L}_f(\lambda, \delta)) + \lambda F_x(x, \gamma, K) - h(x, \hat{L}_f(\lambda, \delta))\}
\]

3.19

\[
\dot{x} = F(x, \gamma, K) - h(x, \hat{L}_f(\lambda, \delta))
\]

3.20

\[x(0) = x_0\]

3.21

\[
\lambda(T) \geq 0 \quad x(T) \geq 0 \quad \lambda(T)x(T) = 0
\]

3.22

Substituting \( x(t, \beta) \) and \( \lambda(t, \beta) \) back into (3.19 - 3.22), the following results are obtained: \( \beta = (P_a, P_f, P_i, \rho, \omega, E_a, A, \gamma, K) \) is the vector of exogenous parameters.

\[
\dot{\lambda}(t, \beta) = \rho \lambda(t, \beta) - \{P_f h_2(x(t, \beta), \hat{L}_f(\lambda, \delta)) + \lambda F_x(x(t, \beta), \gamma, K) - h(x(t, \beta), \hat{L}_f(\lambda, \delta))\}
\]

3.23

\[
\dot{x}(t, \beta) = F(x(t, \beta), \gamma, K) - h(x(t, \beta), \hat{L}_f(\lambda, \delta))
\]

3.24

\[x(0, \beta) = x_0\]

3.25

\[
\lambda(T, \beta) \geq 0 \quad x(T, \beta) \geq 0 \quad \lambda(T, \beta)x(T, \beta) = 0
\]

3.26

The boundary conditions of 3.26 are:

(a) \( \lambda(T, \beta) \geq 0 \Rightarrow x(T, \beta) = 0 \)

(b) \( x(T, \beta) \geq 0 \Rightarrow \lambda(T, \beta) = 0 \)
The first condition indicates that the local community harvests forest resources to depletion within the planning period. The second condition states that there will be a positive stock of forest left over in the terminal period. Hence, the shadow price at the terminal time is zero. However, in a protected forest, complete depletion of resources within the planning horizon may not occur. Therefore, the following analysis is related to the second situation described above.

4.1.2.1 Agricultural Product Price

Differentiation of (3.23 - 3.26) with respect to price of agricultural products

\[
\frac{\partial \lambda (t, \beta)}{\partial p_a} = \lambda_{pa} = \{p + h_x(t, \beta_0) - F_x(t, \beta_0)\} \lambda_{\beta_0} + \{(\lambda - P_f) \lambda_{\beta_0} - \lambda F_x(t, \beta_0)\} x_{p_a} \tag{3.27}
\]

\[
\{p + h_x(t, \beta_0) - F_x(t, \beta_0)\} \Rightarrow a_{11}(t, \beta_0) > 0
\]

\[
\{(\lambda - P_f) \lambda_{\beta_0} - \lambda F_x(t, \beta_0)\} \Rightarrow a_{12}(t, \beta_0) > 0
\]

\[
\frac{\partial \lambda (t, \beta)}{\partial p_a} = \lambda_{pa} = \left\{-h_x(t, \beta_0) \frac{dF_x}{d\lambda}(t, \beta_0)\right\} \lambda_{\beta_0} + X_{\beta_0}(F_x(t, \beta_0) - h_x(t, \beta_0)) - h_x(t, \beta_0) \frac{dF_x}{d\lambda}(t, \beta_0) \tag{3.28}
\]

From equations (3.27 and 3.28) respectively,

\[
\{p + h_x(t, \beta_0) - F_x(t, \beta_0)\} \Rightarrow a_{11}(t, \beta_0) > 0
\]

\[
\{(\lambda - P_f) \lambda_{\beta_0} - \lambda F_x(t, \beta_0)\} \Rightarrow a_{12}(t, \beta_0) > 0
\]

\[
\left\{-h_x(t, \beta_0) \frac{dF_x}{d\lambda}(t, \beta_0)\right\} \Rightarrow a_{21}(t, \beta_0) > 0
\]

\[
\{F_x(t, \beta_0) - h_x(t, \beta_0)\} \Rightarrow a_{22}(t, \beta_0) < 0
\]

\[
x_{p_a}(0) = 0 \tag{3.29}
\]

\[
\lambda_{p_a}(T) = 0 \tag{3.30}
\]
Assuming that the solution to (3.27 - 3.30) denoted by $\lambda_{p_e}(t, \beta_0)$ and $x_{p_e}(t, \beta_0)$ exists and is continuous in $(t, \beta_0) \forall (t, \beta_0) \in (0, T)$, the functions $\lambda_{p_e}(t, \beta_0)$ and $x_{p_e}(t, \beta_0)$ describe the impact of changes in the market price of the agricultural commodity on the entire path of forest resource stock and its current shadow price.

Qualitative properties of the differential equation system are as follows:

$$x_{p_e}(t, \beta_0) \geq 0 \forall t \in (0, T_0)$$

$$\lambda_{p_e}(t, \beta_0) \leq 0 \forall t \in (0, T_0)$$

This indicates how an increase in the price of the agricultural product leads to higher equilibrium forest resource stock in the optimal path. Once farming becomes a lucrative business, households tend to substitute more labor to agricultural activities, which leads to reductions in labor allocation for extraction activities.

3.1.2.2 Technical Efficiency in Agriculture

Differentiation of 3.23-3.26 with respect to the coefficient of agricultural efficiency yields

$$\dot{\lambda}_{x_e} = a_{11}(t, \beta_0)\lambda_{x_e} + a_{12}(t, \beta_0)x_{x_e}$$

3.31

$$\dot{x}_{x_e} = a_{21}(t, \beta_0)\lambda_{x_e} + a_{22}(t, \beta_0)x_{x_e} - h_1(t, \beta_0)\frac{dL_f}{dE_a}(t, \beta_0)$$

3.32

$x_{x_e}(0) = 0$

3.33

$\lambda_{x_e}(T_0) = 0$

3.34

The qualitative properties of the above equation system are:

$$x_{x_e}(t, \beta_0) \geq 0 \forall t \in (0, T_0)$$
\[ \lambda_{x_n}(t, \beta_0) \leq 0 \forall t \in (0, t_0) \]

These results show that increases in technical efficiency for agriculture in periphery areas of the protected forest increases the equilibrium stock of forest biomass hence decreasing its shadow price.

3.1.3 Phase Diagram (Increase in Efficiency for Agriculture)

To determine the general directions that streamlines take, partially differentiate 3.31 and 3.32 (Chiang, 1992).

From 3.31  
\[ \frac{\partial \dot{x}_{E_n}}{\partial x_{E_n}} = a_{12}(t, \beta_0) < 0 \]  \(3.35\)

From 3.32  
\[ \frac{\partial \dot{x}_{E_n}}{\partial \lambda_{E_n}} = a_{21}(t, \beta_0) > 0 \]  \(3.36\)

According to 3.35, as \( x \) increases, \( \dot{x} \) follows the \((+, 0, -)\) sign sequence, hence \( \lambda \) arrowheads should point upward to the left of \( \dot{x} = 0 \) curve and downward to the right of it. Similarly, 3.36 indicates that, \( \dot{x} \) should follow \((- , 0, +)\) sign sequence as \( \lambda \) increases. Therefore, the \( \dot{x} \) arrowheads should point westward below \( \dot{x} = 0 \) curve and eastward above it.

An increase in \( E_n \) shifts \( \dot{x} = 0 \) to right, hence increases the equilibrium stock of forest biomass and decreases its shadow price (Figure 3.1)
Figure 3.1. Effect of technical efficiency in agriculture on equilibrium forest resource stock.
CHAPTER 4

DATA INFORMATION

4.1 Approach

The study was conducted in the peripheries of natural forest areas of the Badulla district in Sri Lanka (Appendix A) which lies in mid-country intermediate zone. The Badulla district plays an important role for the forestry sector in Sri Lanka and is among the four districts selected for the forest resources management sector project. The Badulla district is comprised of a wide range of natural forests with 19.6% of the total land area in the district being devoted to natural forests (Appendix B). Among the natural forest reserves in the district, five areas were selected for the research (i.e., Dunhinda, Kithulahela, Galagadbedda, Bibilehela and Welanwitita reserves). These forest reserves typically represent the natural forest cover of the district as well as the similar forest types in Sri Lanka.

The socio-economic situation of the households and their interaction with the forest resources was considered in selecting the study sites. For example, the average monthly household income of communities in this district is approximately 50 US $. The incidence of poverty in the study area is estimated to be over 30 percent (ADB, 1997). With this level of poverty and over 15 percent unemployment, pressure on natural forests is high. The household’s primary income source is agriculture. Secondary income sources are homegardening, off-farm employment, and animal husbandry. Households living near peripheries of the above natural forests also extract forest resources. These include products such as fruits, vegetables, mushrooms, yams, spices, bush meat, medicinal products, poles, rattan, kithul products (Caryota uranes) and fuelwood. Therefore the
setting, which includes socio-economic factors and the natural environment surrounding the identified forest reserves, is appropriate for analyses and testing of objectives and research hypotheses for this study.

4.2 Sample

Determining the appropriate sample size is a most crucial step in any research study. To obtain a statistically sound result, the approach described by Hamburg (1987) and Yamane (1967) was utilized. The calculation of appropriate sample size is as follows:

\[ n = \left( \frac{Z(\alpha/2)\sigma}{E} \right)^2 \]  

Where:

- \( n \) = sample size
- \( Z \) = the two tail z value with the appropriate confidence level
- \( \sigma \) = population standard deviation
- \( E \) = precision level

In agricultural research, 95 percent confidence interval is normally used. Based on estimation of forest dependency from the pilot survey conducted in April - May 2003, the estimated population standard deviation was calculated. The parameters required to estimate sample size are as follows:

- \( E = 314.65 \) (1/10 of standard deviation)
- \( \alpha = 0.05 \)
- \( Z = 1.96 \)
- \( \sigma = 3146.5 \)
Utilizing this information and equation 4.1, a desired sample size of 382 was obtained.

4.3 Survey Design

Prior to implementation of the survey, pre-testing was conducted among randomly selected households in two forest peripheries during April-May, 2003. Field surveys were conducted during the period of September, 2003-January, 2004 using a structured questionnaire. This was followed by another field visit during May-June, 2004 to re-check the data gathered during field surveys and especially to verify the valuation of forest products. Standardized interviewing techniques (Fowler and Mangione, 1990) were used in order to minimize interviewing related error.

Basic information such as location of forest and villages was also obtained from the District Forest Office (DFO) and the Range Forest Office (RFO) in Badulla. Demographic information related to villages in forest peripheries were collected from the statistical handbooks of the divisional secretariats in Soranathota, Passara, Meegahakivula and Haldummulla in the Badulla district.

The data were collected in several villages in the forest peripheries of Dunhinda, Galagodabedda, Kithulanahela, Bibilehela and Welanwita forest areas. A total of 2923 families were residing in the selected villages. A total of 467 households were selected for the survey based on the stratified random sampling procedure. However, due to incomplete information, only 442 surveys were used for the analysis. Usable responses in each forest site are: Dunhinda (163), Kithulanahela (95), Galagodabedda (92), Bibilehela (43), and Welanwita (48). Households who were not engaged in collection of the forest goods in the survey year were excluded from the analysis.
The questionnaire asks for demographic information about the household characteristics, inputs and output for each crop produced, types of forest goods collected, quantity of forest goods extracted, revenues from other diversified income sources, socio-economic and physical information related to forest extraction, etc. Time of conducting surveys, homogeneity of the educational background of the interviewees, and simplicity of the questionnaire format were considered as quality control measures for obtaining accurate information.

4.4 Data Sources

Information on farm returns from random samples of households for production activities such as paddy and other field crops were collected. Information was collected on the total value of agricultural outputs, because farmers generally practice mixed cropping, in which more than one crop is grown on a piece of land at the same time. Inputs such as land area under cultivation, human labor and other inputs such as inorganic fertilizer, and pesticides were also recorded. Socio-economic variables, such as age, farming experience and the level of education of the farmers were also recorded. Agricultural extension assistance received by the farmer, nutrition and gender status of the head of the household were also recorded. Energy intake of a household is the sum of energy values that could be obtained from each food item consumed in the household. The household head’s meal each day of the reference week is recorded in the survey schedule and this information was used to calculate the per-capita energy intake per day of the household as stipulated by the household income and expenditure survey 2002, by the Department of Census and Statistics of Sri Lanka. Per capita energy intake of the household head was calculated using food composition tables for Sri Lanka (see Perera et al., 1979).
Identification of NTFPs (fruits, vegetables, mushrooms, yams, spices, bee honey, wild meat, medicinal products, poles etc.), and fuelwood used by peripheral villagers, quantities extracted and time spent by households for collection, rate of extraction was performed. In quantifying NTFPs, most of the information was obtained by direct questioning of respondents. Valuing forest goods is a difficult and challenging task hence only few studies have attempted rigorous treatment of estimating the economic value of forest goods (Reddy and Chakravarty, 1999). For this study, market-based approaches in valuing forest goods were used. Non-market valuation techniques were not used as total forest biodiversity is not measured in the study. However, due to a short time horizon, relatively homogenous population and low variation of price in local markets, it is assumed that the market based approach in valuing forest goods would not lead to major mis-specifications hence it is unlikely that it would fundamentally change the results. The economic value of the NTFPs was assessed using forest gate prices, the opportunity cost of time and the prices of closest substitutes (see Godoy et al., 1993 and Vedeld et al., 2004). Forest gate prices were used to assess the value of products such as fruits, vegetables, mushrooms, wild meat, bee honey, rattan (*Calamus* spp), kithul (*Caryota urenus*) products, spices and marketable medicinal products. Opportunity cost of time was used to value products such as thatching materials, poles, cut grass and non-marketable medicinal products. As extraction is a time-consuming activity, the opportunity cost of time makes sense in approximating the value of extracted products. In calculating the opportunity cost of time, wages from rural labor market was considered. Rural wage rates were determined based on gender hence these differences were also accounted for in calculation (see Gittinger, 1982 and McDiarmid, 1977 in calculating
opportunity cost of time). The value of fuelwood was determined using price of the closest substitute (price of marketable fuelwood). Based on the above information, the aggregate economic value of NTFPs for each household was calculated.

Farmer wealth was measured by the value of nine assets (i.e., cows, buffaloes, goats, poultry, tractors, bicycles, radios, televisions, and farm equipment used with animals). To value physical assets, village prices at the time of survey were used. Off-farm income was calculated as income received by non-farm and non-extraction activities. Household members have to walk to the forest for extraction activities. The distance from their home to the forest location most often visited was measured in kilometers. Average time spent by each household on a single trip was recorded. The number of trips that households take to the forest for gathering activities was also recorded. The number of years of experience in forest gathering was recorded as a proxy for accumulated forest knowledge.

Secondary data were mainly gathered from government publications, sectoral studies, and previous research studies. Forestry maps were obtained from the Department of forest conservation.
CHAPTER 5
ESTIMATION OF TECHNICAL EFFICIENCY

This section presents the theoretical and empirical models and estimation results in relation to technical efficiency estimates for farming in forest peripheries. The first part of the chapter deals with the translog production function and determining factors associated with technical inefficiency. Subsequently, this chapter discusses the Data Envelopment Analysis (DEA) model and its analytical results.

5.1 Theoretical Model (The Stochastic Frontier Model)

Since the basic stochastic frontier model was first proposed by Aigner et al., (1977) and Muecusen and Van den Broeck (1977), various other models have been suggested and applied in the analysis of cross sectional and panel data. Reviews of some of these models and their applications are given by Battese (1992), Bravo-Ureta and Pinherio (1993), and Coelli (1995). Some models have been proposed in which the technical inefficiency effects in the stochastic frontier model are also modeled in terms of other observable explanatory variables (see Kumbhakar et al., 1991; Huang and Liu, 1994; Battese and Coelli, 1995).

The stochastic frontier production function is defined by:

\[ Y_i = f(x_i, \beta) \exp(V_i - U_i) \quad i = 1, \ldots, N \quad 5.1 \]

Where \( V_i \) is a random error having zero mean, which is associated with random factors (e.g., measurement errors in production, weather, industrial action, etc.) not under the control of the firm.
This stochastic frontier model was independently proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977). The model is such that the possible production, $Y_i$, is bounded above by the stochastic quantity, $f(x_i; \beta) \exp(V_i)$; hence the term stochastic frontier. The random errors, $V_i; i=1,2, \ldots , N$ were assumed to be independently and identically distributed as $N(0, \sigma^2)$ random variables, independent of the $U_i$'s which were assumed to be non-negative truncations of the $N(0, \sigma^2)$ distribution (i.e. half normal distribution) or have exponential distribution. Meeusen and Van den Broeck (1977) considered only the case in which the $U_i$'s had exponential distribution (i.e., $\gamma$ distribution with parameters $r = 1$ and $\lambda > 1$) and noted that the model was not as restrictive as the one parameter $\gamma$ distribution (i.e., $\gamma$ distribution with parameters $r = n$ and $\lambda > 1$) considered by Richmond (1974).

The basic structure of the stochastic frontier model (5.1) is depicted in Figure 5.1 in which the productive activities of two firms, represented by $i$ and $j$, are considered. Firm $i$ uses inputs with values given by (the vector) $x_i$ and produces output, $Y_i$, but the frontier output, $Y_i^*$, exceeds the value on the deterministic production function, $f(x_i; \beta)$, because its productive activity is associated with favorable conditions for which the random error, $V_i$ is positive. However, firm $j$ uses inputs with values given by (the vector) $x_j$ and produces output, $Y_j$ which has corresponding frontier output, $Y_j^*$ which is less than the value on the deterministic production function, $f(x_j; \beta)$, because its productive activity is associated with unfavorable conditions for which the random error $V_j$ is negative. In both cases the observed production values are less than the
corresponding frontier values, however the (unobservable) frontier production values lie above or below the deterministic production function depending on the existence of favorable or unfavorable conditions beyond the firm's control.

![Stochastic frontier production function](image)

Figure 5.1. Stochastic frontier production function.

Given the assumptions of the stochastic frontier model (5.1), inference about the parameters of the model can be based on the maximum likelihood estimators because the standard regularity conditions hold. Aigner, Lovell and Schmidt (1977) suggested that the maximum-likelihood estimates of the parameters of the model be obtained in terms of the parameterization, \( \sigma^2 + \sigma^2 = \sigma^2 \) and \( \lambda = \sigma / \sigma \). Rather than use the non-negative parameters, \( \lambda \) (i.e., the ratio of the standard deviation of the \( N(0, \sigma^2) \) distribution
involved in specifying the distribution of the non-negative $U_i$'s to the standard deviation of the symmetric errors, $V_i$, Battese and Corra (1977) considered the parameter, $\gamma = \sigma^2 / (\sigma^2 + \sigma^2)$, which is bounded between zero and one.

Technical efficiency of an individual firm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by that firm. Thus, the technical efficiency of firm $i$ in the context of the stochastic frontier production function (5.1) is the same expression as for the deterministic frontier model (Appendix C), namely $TE_i = \exp(-U_i)$ i.e.,

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(x_i, \beta) \exp(V_i - U_i) / f(x_i, \beta) \exp(V_i)}{f(x_i, \beta) \exp(V_i)} = \exp(-U_i)$$

Although the technical efficiency of a firm associated with the deterministic and stochastic frontier models are the same, they have different values for the two models (Battese, 1992). As shown in figure 6.1, technical efficiency of firm $j$ is greater under the stochastic frontier model than for the deterministic frontier, i.e., $Y_j / Y_j^* > [Y_j / f(x_j, \beta)]$. That is firm $j$ is judged technically more efficient relative to the unfavorable conditions associated with its productive activity (i.e., $V_j < 0$) than if its production is judged relative to the maximum associated with the value of deterministic function, $f(x_j, \beta)$. Further, firm $i$ is judged technically less efficient relative to its favorable conditions than if its production is judged relative to the maximum associated with the value of the deterministic function, $f(x_i, \beta)$. However, for a given set of data,
the estimated technical efficiencies obtained by fitting a deterministic frontier will be less than those obtained by fitting a stochastic frontier, because the deterministic frontier will be estimated such that no output values will exceed it (Battese, 1992).

5.2 Empirical Model

In the first phase of the analysis, technical efficiency effects for a cross section of rural agricultural households in the periphery of the natural forest were modeled in terms of input variables in the production process. Various statistical hypotheses were tested for the smallholder farmers and their technical efficiencies of production are predicted. The empirical model of technical efficiency was based on the stochastic production function proposed by Battese and Coelli (1995).

Rural agricultural households generally cultivate different crops in their farmlands, therefore this practice renders the single crop production model to be infeasible. In the case of multiple outputs, the dependent variable in the production model is measured in terms of the total value of agricultural outputs or production. Inputs can be categorized into three groups: land, labor and other variable inputs.

The stochastic frontier model to be estimated is defined by:

\[
\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_j \ln X_{ij} + \sum_{j<k=1}^{6} \beta_{jk} \ln X_{ij} \ln X_{ki} + V_i - U_i
\]

Where \( \ln \) represent the natural logarithm

the subscript, \( i \), indicates the \( i \)th farmer in the sample \((i = 1,2, \ldots, n)\).

\( \ln Y_i \) represents the natural logarithm of the value of farm output

\( \ln X_1 \) represents the natural logarithm of the total area of land (in ha) under cultivation (Extent)
$lnX_2$ represents the natural logarithm of family labor in man-days (Flabor)

$lnX_3$ represents the natural logarithm of hired labor in man-days (Hlabor)

$lnX_4$ is the natural logarithm of the quantity of inorganic fertilizer applied (Ifert)

$lnX_5$ is the natural logarithm of the quantity of organic fertilizer applied (Ofert)

$lnX_6$ is the natural logarithm of the quantity of pesticides applied (Pest)

$\beta_j$'s are unknown parameters to be estimated

$\nu_i$'s are assumed to be independent and identically distributed normal random errors having zero mean and unknown variance, $\sigma_{\nu}^2$; $U_i$'s are non-negative random variables, called technical inefficiency effects, which are assumed to be independently distributed such that $U_i$ is defined by the truncation (at zero) of the normal distribution with mean, $\mu_i$ and variance $\sigma^2$.

$$U_i = \delta_0 + \delta_1Z_{1i} + \delta_2Z_{2i} + \delta_3Z_{3i} + \delta_4Z_{4i} + \delta_5Z_{5i} + \delta_6Z_{6i}$$  

5.3

Where:

$Z_{1i}$ is the age of the household head in years (Age)

$Z_{2i}$ represents the formal education (Edu) of the household head (1 if household head has received secondary education or otherwise 0)

$Z_{3i}$ is the number of years of experience in farming (Exp) of the household head

$Z_{4i}$ represents the number of hours of extension assistance (Exten) received by the household head

$Z_{5i}$ is the nutritional level (Nutri) of the household head measured by average daily intake of kilocalories (kcal)
\( Z_{6i} \) is gender (Gen) 1 if the household head is male or otherwise zero

\( \delta \)'s are known as scalar parameters

The model for the technical inefficiency effects, defined by equation (5.3) specifies that the technical inefficiency effects of the stochastic frontier (5.1) are a function of the age, gender, education, nutritional status, experience of the household head, and the hours of extension advice they receive.

It is hypothesized that increased formal education, \textit{ceteris paribus}, is expected to reduce technical inefficiency. Older farmers are expected to increase inefficiency (see Battese and Coelli, 1992; Burki and Terrell, 1998; Ekanayake and Jayasuriya, 1987; Kalirajan and Flinn, 1983) partly because older farmers tend to be less adaptable to new technical developments. It is also hypothesized that increased experience in farming results in lower values of technical inefficiency (Carter and Cubbage, 1995).

More advice from extension workers, \textit{ceteris paribus}, is expected to reduce technical inefficiency effects, which can be categorized as institutional characteristics. The impact of nutrition on labor productivity has been analyzed by number of authors (Strauss, 1996, and Deolalikar, 1988). It is hypothesized that households with access to more nutritional diets result in lower values of technical inefficiency. According to the gender division among rural households in Sri Lanka, farming is mainly done by males. Male household heads possess more skills for farming activities. Therefore, if the household head is male, then a lower technical inefficiency value is expected.

Kumbhakar et al., (1991) argued against use of the two-step procedure for studies examining factors affecting technical inefficiency. The problems highlighted were:
a. technical inefficiency may be correlated with the inputs causing inconsistent estimates of the parameters as well as technical inefficiency

b. the standard ordinary least squares results in the second step may not be appropriate since technical inefficiency—the dependent variable—is one sided.

c. the estimated value of inefficiency should be non-positive for all observations

d. meaning of the residual term in the two-step regression is not clear.

Hence in this analysis, a single step procedure was performed.

5.2.1 Results and Discussion

The data set consists of 442 households from five different forest reserves in the Badulla district. Bibilehela and Welanvita forest reserves are contiguous, hence considered as one reserve. Summary statistics with regard to the key variables are given in Appendix D. The Chow test was performed to determine whether pooling the data by different forest sites was appropriate. The results are summarized in Appendix E. Pooling data between different forest sites in the translog frontier model was rejected except for the forest reserves of Kithulanahela vs Galagodabedda and Kithulanahela vs Bibilehela–Welanvita. In addition, the hypothesis of pooling data in a forest dependency model was rejected except for the forest reserves of Galagodabedda vs Bibilehela–Welanvita. As the forest dependency model depends on the translog frontier model, pooling data was not possible in the analysis. Each forest and its peripheral villages has its own natural and socio-economics environment. The causes for site variation may also be explained by the coefficient of variation for important variables and are presented in Appendix F. In general compared to other variables, income measures from different sources showed highest variability for all sites. Hence, separate analysis was followed for each forest site.
The maximum likelihood estimates for all the parameters of the stochastic frontier and inefficiency model were simultaneously obtained by using the program, Frontier Version 4.1 (Coelli, 1996), which estimates the variance parameters in terms of the parameterization. The single step procedure was performed where factors believed to have an effect on technical inefficiency were simultaneously regressed with factors included in frontier model. The hypothesis of constant return to scale \( (H_0 = RTS = 1) \) based on restricted least squares couldn’t be rejected for the Kithulanahela, Galagodabedda, and Bibilehela-Welanvita forest reserves as \( F \) statistics (i.e., 2.12, 0.71, and 0.13 respectively) were insignificant with respected p-values of 0.14, 0.40, and 0.72. For Dinhhinda forest reserve, \( F \) statistics (3.76) was at the margin of rejection (\( p = 0.05 \)). The analytical results of the maximum likelihood (ML) estimates of the translog production frontier are shown in Tables 5.1 and 5.2. The ML estimate of the variance parameter, \( \gamma \), is close to 1 for all sites and significantly different from zero, hence assuring the stochastic nature of the production function. These results indicate that the vast majority of residual variation is due to the inefficiency effect, \( U_i \), while the random error \( V_i \), is approximately zero.

It is observed that the one-sided generalized likelihood ratio test of \( \gamma = 0 \) for Dinhhinda, Kithulanahela, Galagodabedda and Bibilehela-Welanvita forest reserves were 104.09, 78.82, 6.12, and 39.65 respectively, which exceeds the 5% critical value. Therefore, the traditional average response function is not an adequate representation of the data, which further assures its stochastic nature.

For the ML estimation analysis of the Dinhhinda forest reserve, factors such as the extent of farming (Area), family labor (Flabor), hired labor (Hlabor), and application of inorganic fertilizer (Ifer) exhibited positive and statistically significant relationships with
farm income. However, application of organic fertilizer (Ofer) and pesticides (Pest) did not have a significant relationship on farm income in this analysis. Generally, frequency and extent of use of organic fertilizers and pesticides in farming for the Dunhinda area are low.

For the Kithulanhela forest reserve, factors such as the Area, Flabor, Ofer, and Pest exhibited positive and statistically significant relationships with farm income. However, Hlabor exhibited an unexpected negative and significant relationship. One possible reason may be that a few tobacco farmers with high returns while employing less hired labor overshadowed the hired labor in the rest of the sample. Another reason for this result could also be attributed to data measurement problems encountered from the survey. Normally in rural areas in Sri Lanka, farming is done by communal labor groups, where farmers help each other especially during field preparation, planting and harvesting. Perhaps there may be errors in reporting data in relation to hired labor employed for farming. Application of Ofer showed an unexpected negative sign, however, it did not have a significant relationship on farm income in this analysis.

For the Galagodbedda forest reserve, all factors had positive signs, however only Extent, Flabor, and Ofer showed significant relationships. For the Bibilehela–Welanhita forest reserve, factors excluding Flabor and Hlabor had the expected positive sign, but only Extent and Ofer showed statistical significance. Although factors such as Flabor and Hlabor showed negative relationships, these were not significant.

The overall mean technical efficiency for farming in the Dunhinda, Kithulanhela, Galagodbedda and Bibilehela–Welanhita forest reserves are 0.67, 0.71, 0.73, and 0.69 respectively. Table 5.3 shows that farms were distributed throughout the technical efficiency range.
In the inefficiency model, farmer’s age had the expected positive sign except for the Bibilehela-Welanvita forest reserve, however was significant only for the Kithulanahela and Galagodabedda forest reserves. However, it was significant only for the Kithulanahela and Galagodabedda forest reserves. Increasing age by 1 year showed an increase in technical inefficiency by 0.01 and 0.04 for these forest reserves respectively.

Results indicate that personal characteristics such as education (Edu) and experience in farming (Exp) had negative relationships in all forest reserves. Edu is statistically significant in all cases however, Exp is significant only for the Dunhinda and Kithulanahela forest reserves. Accordingly, receiving secondary education showed reduction of technical inefficiency by 0.42, 0.38, 0.39, and 0.33 for the Dunhinda, Kithulanahela, Galagodabedda, and Bibilehela-Welanvita forest reserves respectively. Education enables household heads to access and utilize information on crop production and management. Utilizing this information in production decreases technical inefficiency. Farmers with more experience are generally technically less inefficient users of resources. Each additional year of farming experience showed reductions in technical inefficiency of 0.02 and 0.05 for the Dunhinda and Kithulanahela forest reserves respectively.
### Table 5.1. ML estimates for the Dunhinda and Kithulanhela forest reserves.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda forest Reserve</th>
<th></th>
<th>Kithulanhela forest reserve</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Standard error</td>
<td>t-ratio</td>
<td>Coefficient</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>5.91</td>
<td>0.72</td>
<td>8.19*</td>
<td>4.57</td>
</tr>
<tr>
<td>$\beta_1$ (Extent)</td>
<td>1.23</td>
<td>0.34</td>
<td>3.59*</td>
<td>3.46</td>
</tr>
<tr>
<td>$\beta_2$ (Flabor)</td>
<td>1.21</td>
<td>0.38</td>
<td>3.16*</td>
<td>1.98</td>
</tr>
<tr>
<td>$\beta_3$ (Habor)</td>
<td>0.04</td>
<td>0.60(-02)</td>
<td>5.97*</td>
<td>-0.24</td>
</tr>
<tr>
<td>$\beta_4$ (Ifer)</td>
<td>0.23</td>
<td>0.04</td>
<td>5.52*</td>
<td>-0.02</td>
</tr>
<tr>
<td>$\beta_5$ (Ofer)</td>
<td>-0.64(-02)</td>
<td>0.02</td>
<td>-0.29</td>
<td>0.11</td>
</tr>
<tr>
<td>$\beta_6$ (Pest)</td>
<td>0.05</td>
<td>0.04</td>
<td>1.36</td>
<td>0.27</td>
</tr>
<tr>
<td>$\beta_{11}$ (Extent²)</td>
<td>0.24</td>
<td>0.05</td>
<td>5.19*</td>
<td>0.87</td>
</tr>
<tr>
<td>$\beta_{12}$ (Flabor²)</td>
<td>-0.08</td>
<td>0.04</td>
<td>-2.15*</td>
<td>-0.22</td>
</tr>
<tr>
<td>$\beta_{13}$ (Habor²)</td>
<td>0.02</td>
<td>0.02</td>
<td>1.19</td>
<td>0.18</td>
</tr>
<tr>
<td>$\beta_{14}$ (Ifer²)</td>
<td>0.04</td>
<td>0.01</td>
<td>3.09*</td>
<td>0.48(-02)</td>
</tr>
<tr>
<td>$\beta_{15}$ (Ofer²)</td>
<td>0.02</td>
<td>0.01</td>
<td>1.67</td>
<td>-0.12</td>
</tr>
<tr>
<td>$\beta_{16}$ (Pest²)</td>
<td>-0.14</td>
<td>0.02</td>
<td>-8.58*</td>
<td>0.83(-02)</td>
</tr>
<tr>
<td>$\beta_{17}$ (Extent x Flabor)</td>
<td>0.12</td>
<td>0.07</td>
<td>1.69</td>
<td>-0.71</td>
</tr>
<tr>
<td>$\beta_{18}$ (Extent x Habor)</td>
<td>-0.03</td>
<td>0.02</td>
<td>-2.71*</td>
<td>0.30</td>
</tr>
<tr>
<td>$\beta_{19}$ (Extent x Ifer)</td>
<td>-0.19</td>
<td>0.03</td>
<td>-7.67*</td>
<td>-0.12(-02)</td>
</tr>
<tr>
<td>$\beta_{20}$ (Extent x Ofer)</td>
<td>0.02</td>
<td>0.02</td>
<td>1.09</td>
<td>-0.26</td>
</tr>
<tr>
<td>$\beta_{21}$ (Flabor x Habor)</td>
<td>-0.03</td>
<td>0.03</td>
<td>-0.99</td>
<td>-0.24</td>
</tr>
<tr>
<td>$\beta_{22}$ (Flabor x Ifer)</td>
<td>-0.08</td>
<td>0.03</td>
<td>-2.45*</td>
<td>0.01</td>
</tr>
<tr>
<td>$\beta_{23}$ (Flabor x Ofer)</td>
<td>-0.03</td>
<td>0.03</td>
<td>-1.24</td>
<td>0.28</td>
</tr>
<tr>
<td>$\beta_{24}$ (Flabor x Pest)</td>
<td>-0.07</td>
<td>0.01</td>
<td>-7.43*</td>
<td>-0.10</td>
</tr>
<tr>
<td>$\beta_{25}$ (Habor x Ifer)</td>
<td>0.91(-05)</td>
<td>0.12(-05)</td>
<td>7.86*</td>
<td>0.23(-05)</td>
</tr>
<tr>
<td>$\beta_{26}$ (Habor x Ofer)</td>
<td>0.25(-05)</td>
<td>0.68(-06)</td>
<td>3.76*</td>
<td>0.22(-05)</td>
</tr>
<tr>
<td>$\beta_{27}$ (Habor x Pest)</td>
<td>0.43(-05)</td>
<td>0.54(-06)</td>
<td>7.99*</td>
<td>-0.96(-05)</td>
</tr>
<tr>
<td>$\beta_{28}$ (Ifer x Ofer)</td>
<td>-0.72(-05)</td>
<td>0.82(-06)</td>
<td>-8.79*</td>
<td>0.12(-04)</td>
</tr>
<tr>
<td>$\beta_{29}$ (Ifer x Pest)</td>
<td>0.28(-05)</td>
<td>0.11(-05)</td>
<td>2.50*</td>
<td>-0.13(-04)</td>
</tr>
<tr>
<td>$\beta_{30}$ (Ofer x Pest)</td>
<td>-0.37(-06)</td>
<td>0.12(-05)</td>
<td>-0.30</td>
<td>-0.46(-05)</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>4.13</td>
<td>1.25</td>
<td>3.29*</td>
<td>7.74</td>
</tr>
<tr>
<td>$\delta_1$ (Age)</td>
<td>0.34(-02)</td>
<td>0.01</td>
<td>0.29</td>
<td>0.02</td>
</tr>
<tr>
<td>$\delta_2$ (Edu)</td>
<td>-0.42</td>
<td>0.14</td>
<td>-2.97*</td>
<td>-0.38</td>
</tr>
<tr>
<td>$\delta_3$ (Exp)</td>
<td>-0.02</td>
<td>0.01</td>
<td>-1.98*</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\delta_4$ (Extwt)</td>
<td>-0.46</td>
<td>0.19</td>
<td>-2.31*</td>
<td>-0.62</td>
</tr>
<tr>
<td>$\delta_5$ (Nutri)</td>
<td>-0.17(-02)</td>
<td>0.77(-03)</td>
<td>-2.26*</td>
<td>-0.48(-02)</td>
</tr>
<tr>
<td>$\delta_6$ (Gen)</td>
<td>-1.16</td>
<td>0.30</td>
<td>-3.89*</td>
<td>-0.62</td>
</tr>
<tr>
<td>Sigma Sq</td>
<td>0.72</td>
<td>0.11</td>
<td>6.71*</td>
<td>0.54</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.99</td>
<td>0.83(-07)</td>
<td>0.12(+08)*</td>
<td>0.99</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
Table 5.2. ML estimates for the Galagodabedda and BibileheIa-Welanvita forest reserves.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Galagodabedda forest Reserve</th>
<th>BibileheIa-Welanvita forest reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Standard error</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>9.21</td>
<td>0.69</td>
</tr>
<tr>
<td>$\beta_1$ (Extent)</td>
<td>2.90</td>
<td>0.71</td>
</tr>
<tr>
<td>$\beta_2$ (Flabor)</td>
<td>0.34</td>
<td>0.14</td>
</tr>
<tr>
<td>$\beta_3$ (Hlabor)</td>
<td>0.49(-02)</td>
<td>0.07</td>
</tr>
<tr>
<td>$\beta_4$ (Ifer)</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>$\beta_5$ (Ofer)</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>$\beta_6$ (Pest)</td>
<td>-0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>$\beta_{11}$ (Extent²)</td>
<td>0.39</td>
<td>0.15</td>
</tr>
<tr>
<td>$\beta_{22}$ (Flabor²)</td>
<td>-0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>$\beta_{33}$ (Hlabor²)</td>
<td>-0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>$\beta_{44}$ (Ifer²)</td>
<td>-0.14</td>
<td>0.03</td>
</tr>
<tr>
<td>$\beta_{55}$ (Ofer²)</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>$\beta_{66}$ (Pest²)</td>
<td>-0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>$\beta_{12}$ (Extent x Flabor)</td>
<td>-0.41</td>
<td>0.18</td>
</tr>
<tr>
<td>$\beta_{13}$ (Extent x Hlabor)</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>$\beta_{14}$ (Extent x Ifer)</td>
<td>-0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>$\beta_{15}$ (Extent x Ofer)</td>
<td>-0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>$\beta_{16}$ (Extent x Pest)</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>$\beta_{21}$ (Flabor x Hlabor)</td>
<td>-0.20</td>
<td>0.11</td>
</tr>
<tr>
<td>$\beta_{22}$ (Flabor x Ifer)</td>
<td>0.29</td>
<td>0.07</td>
</tr>
<tr>
<td>$\beta_{23}$ (Flabor x Ofer)</td>
<td>-0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>$\beta_{24}$ (Flabor x Pest)</td>
<td>0.10</td>
<td>0.06</td>
</tr>
<tr>
<td>$\beta_{31}$ (Hlabor x Ifer)</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>$\beta_{32}$ (Hlabor x Ofer)</td>
<td>0.25(-05)</td>
<td>0.18(-05)</td>
</tr>
<tr>
<td>$\beta_{33}$ (Hlabor x Pest)</td>
<td>0.35(-05)</td>
<td>0.27(-05)</td>
</tr>
<tr>
<td>$\beta_{41}$ (Ifer x Ofer)</td>
<td>0.21(-05)</td>
<td>0.35(-05)</td>
</tr>
<tr>
<td>$\beta_{42}$ (Ifer x Pest)</td>
<td>-0.56(-05)</td>
<td>0.32(-05)</td>
</tr>
<tr>
<td>$\beta_{51}$ (Ofer x Pest)</td>
<td>-0.69(-05)</td>
<td>0.28(-05)</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>0.21</td>
<td>0.98</td>
</tr>
<tr>
<td>$\delta_1$ (Age)</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>$\delta_2$ (Edu)</td>
<td>-0.39</td>
<td>0.17</td>
</tr>
<tr>
<td>$\delta_3$ (Exp)</td>
<td>-0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>$\delta_4$ (Extent)</td>
<td>-0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>$\delta_5$ (Nutri)</td>
<td>-0.21(-02)</td>
<td>0.76(-03)</td>
</tr>
<tr>
<td>$\delta_6$ (Gen)</td>
<td>1.99</td>
<td>0.53</td>
</tr>
<tr>
<td>Sigma Sq</td>
<td>0.39</td>
<td>0.05</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.99</td>
<td>0.35(-05)</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
The coefficient for extension contacts (Exten) was negative and significant except for Galagodabedda forest reserve supporting the hypothesis that farmers who receive extension assistance tend to be less inefficient. Accordingly, additional one hour of extension assistance showed reduction of technical inefficiency by 0.46, 0.62, 0.08, and 0.21 for the Dunhinda, Kithulanahela, and Galagodabedda forest reserves respectively.

Nutritional status of the household head was negative and significant, hence households that intake food with more calories tend to be less inefficient. Increasing daily intake of energy by 100 kilocalories showed reduction of technical inefficiency by 0.17, 0.48, 0.21, and 0.62 for the Dunhinda, Kithulanahela, Galagodabedda, and Bibilehela-Welanvita forest reserves respectively. Although farming is dominated by male-headed households in the study sites, interestingly, the gender variable indicated negative and significant relationship with inefficiency for the Dunhinda forest reserve.

The variable gender had an unexpected positive and significant relationship for the Galagodabedda forest reserve. The Galagodabedda forest reserve sample consisted only of six female-headed households, hence male households who are less efficient may outweigh those who are more efficient.

Table 5.3. Technical efficiency ranges in agricultural farms in forest peripheries.

<table>
<thead>
<tr>
<th>Efficiency range</th>
<th>Dunhinda</th>
<th>Kithulanahela</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of farms</td>
<td>% of farms</td>
<td>Number of farms</td>
<td>% of farms</td>
<td>Number of farms</td>
</tr>
<tr>
<td>0.1-0.19</td>
<td>06</td>
<td>3.68</td>
<td>04</td>
<td>4.21</td>
</tr>
<tr>
<td>0.2-0.29</td>
<td>10</td>
<td>6.13</td>
<td>02</td>
<td>2.10</td>
</tr>
<tr>
<td>0.3-0.39</td>
<td>06</td>
<td>3.68</td>
<td>06</td>
<td>6.32</td>
</tr>
<tr>
<td>0.4-0.49</td>
<td>14</td>
<td>8.59</td>
<td>09</td>
<td>9.47</td>
</tr>
<tr>
<td>0.5-0.59</td>
<td>18</td>
<td>11.04</td>
<td>07</td>
<td>7.37</td>
</tr>
<tr>
<td>0.6-0.69</td>
<td>33</td>
<td>20.25</td>
<td>08</td>
<td>8.42</td>
</tr>
<tr>
<td>0.7-0.79</td>
<td>21</td>
<td>12.88</td>
<td>16</td>
<td>16.84</td>
</tr>
<tr>
<td>0.8-0.89</td>
<td>14</td>
<td>8.59</td>
<td>18</td>
<td>18.95</td>
</tr>
<tr>
<td>&gt;0.9</td>
<td>41</td>
<td>25.15</td>
<td>25</td>
<td>26.31</td>
</tr>
</tbody>
</table>

55
5.3 Theoretical Model (Data Envelopment Analysis)

Results of the frontier program do not yield scale efficiency. However, scale efficiency can be detected by Data Envelopment Analysis (DEA). DEA seeks to identify those Decision Making Units (DMUs) which determine an envelopment surface or efficiency frontier. Units that lie below the surface are deemed inefficient and DEA provides a measure of their efficiency relative to those that lie on the surface. DEA establishes two types of envelopment surfaces, namely, Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) surfaces. VRS model produce the measures for pure technical efficiency and CRS model produce the measures for overall technical efficiency. The ratio of CRS efficiency score to VRS efficiency score gives the measure of scale efficiency.

Input-oriented models for VRS and CRS envelopment are as follows.

Stage 1:

\[ \text{VRS}(Y_1, X_1): \min_{\theta, \lambda, s, e_i} \theta \]

Subject to:

\[ \sum_{j=1}^{n} \lambda_j y_j - s = y_1 \]

\[ - \sum_{j=1}^{n} \lambda_j x_{ij} + \theta q_{i1} - e_i = 0 \quad i = 1, \ldots, 6 \text{ inputs} \]

\[ \sum_{j=1}^{n} \lambda_j = 1 \]

\[ \lambda_j \geq 0; \ s \geq 0; \ e_i \geq 0 \]
Stage 2:

\[ VRS_E(y_1, \theta x_1): \min_{\lambda_j, s, e_i} \left[ s + \frac{6}{i-1} \sum_{i=1} e_i \right] \]

Subject to:

\[ \sum_{j=1}^{n} \lambda_j y_1 - s = y_1 \]

\[ - \sum_{j=1}^{n} \lambda_j x_{ij} + \theta' x_{i1} - e_i = 0 \quad i = 1, \ldots, 6 \text{ inputs} \]

\[ \sum_{j=1}^{n} \lambda_j = 1; \]

\[ \lambda_j \geq 0; \quad s \geq 0; \quad e_i \geq 0; \]

where: \( y_j = \) output of \( DMU_j \) \( j = 1, \ldots, 163, 95, 92, \) and 92 farms

respectively

Output = value of farm products/year

\( X_{ij} = \) \( i^{th} \) input of \( DMU_j \) \( i = 1, \ldots, 6 \) inputs (i.e., Land area, Flabor, Hlabor, Ifer, Ofer, and Pest)

\( s = \) output slack

\( e_i = \) \( i^{th} \) input excess

\( \lambda_j = \) weight of \( DMU_j \)

\( \theta' = \) solution to the first stage problem

The corresponding CRS input-oriented model is obtained by dropping the constraint \( \sum_{j=1}^{n} \lambda_j = 1. \)

The input oriented efficiency score for \( DMU_k \) is calculated as follows:
An input efficiency score of 1 indicates that the DMU is efficient and less than 1 indicates inefficiency.

5.3.1 Results and Discussion

DEA was performed using DEAP version 2.1. Results of the frontier program do not yield scale efficiency. However, scale efficiency can be detected by DEA. Technical efficiency scores in the DEA model (CRS, VRS and SE) are shown in Table 5.4. However, these scores are not comparable to efficiency scores gained by frontier analysis.

Table 5.4. Mean efficiency scores in DEA model.

<table>
<thead>
<tr>
<th>Forest reserve</th>
<th>CRSTE</th>
<th>VRSTE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunhinda</td>
<td>0.60</td>
<td>0.68</td>
<td>0.89</td>
</tr>
<tr>
<td>Kithulananahela</td>
<td>0.62</td>
<td>0.71</td>
<td>0.87</td>
</tr>
<tr>
<td>Galagoda Bedda</td>
<td>0.66</td>
<td>0.72</td>
<td>0.86</td>
</tr>
<tr>
<td>Bibilehela-Welanvita</td>
<td>0.67</td>
<td>0.79</td>
<td>0.81</td>
</tr>
</tbody>
</table>

CRSTE: technical efficiency from constant return to scale DEA
VRSTE: technical efficiency from variable return to scale DEA
SE: scale efficiency

While stochastic frontier showed constant returns to scale, the VRS measures of technical efficiency were higher than corresponding CRS technical efficiency for all forest reserves.

The distribution of farms in different efficiency ranges are given in Appendix G. Table 5.5 shows distribution of farms in different return to scale categories. Over fifty percent of the farms in peripheries of all forest reserves showed increasing returns to scale.
Table 5.5. Return to scale in DEA analysis.

<table>
<thead>
<tr>
<th>Forest reserve</th>
<th>IRS No of farms</th>
<th>% of farms</th>
<th>DRS No of farms</th>
<th>% farms</th>
<th>CRS No of farms</th>
<th>% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunhinda</td>
<td>86</td>
<td>52.8</td>
<td>49</td>
<td>30.1</td>
<td>28</td>
<td>17.2</td>
</tr>
<tr>
<td>Kithulananahela</td>
<td>62</td>
<td>65.3</td>
<td>8</td>
<td>8.4</td>
<td>28</td>
<td>29.5</td>
</tr>
<tr>
<td>Galagodabedda</td>
<td>67</td>
<td>72.8</td>
<td>13</td>
<td>14.1</td>
<td>12</td>
<td>13.0</td>
</tr>
<tr>
<td>Bibilehela-</td>
<td>52</td>
<td>56.5</td>
<td>28</td>
<td>30.4</td>
<td>12</td>
<td>13.0</td>
</tr>
<tr>
<td>Welanvita</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IRS: increasing returns to scale  
DRS: decreasing returns to scale  
CRS: constant returns to scale

The above results shows that in addition to pure technical inefficiency, a inefficiency due to scale do exist in the investigated farms. Scale inefficiency is due to
the failing to achieve the optimum scale of operation.
6.1 Theoretical Background

There has been growing interest in developing household economic models for agriculture and tropical forestry. Of those household economic models of interest, those dealing with agriculture productivity and tropical deforestation warrant careful examination and are summarized next.

Shively (2001) developed a model of lowland technical progress and upland activities at a tropical forest margin. A model of lowland agricultural production is combined with a model of labor allocation on a representative upland farm to show how labor productivity, agricultural wages, and the returns from upland activities determine the rate of forest clearing. The empirical analysis based on farm level data from the Philippines demonstrates how agricultural intensification in the form of lowland irrigation development led to an increase in labor demand, an increase in employment of upland inhabitants, and small but significant reductions in rates of forest clearing.

As Shively (2001) pointed out, the impact of technical progress depends on both direct impacts arising in the labor market and the indirect impacts arising in commodity markets. Growth in lowland production tends to pull labor out of upland production. Also, production increased income throughout the lowland economy, causing increased demand for upland products, which resulted in upland households concentrating on commodity production and reducing forest degrading activities.
A labor allocation model of the Bolivian Andes developed by the Bluffstone et al., (2001), examined the hypothesis that better management and regulation translates into time saving for households engaged in forest related activities. Such time saving can then be used in other productive activities such as off-farm employment. Time allocation toward more productive activities and an increase in resource rents translate into increased household income.

The household model developed by Kohlin (1998), explains choice of collection/consumption of biomass among households in Orissa, India, from natural forests (NF), village woodlots (VWL) and the markets. Based on the Kuhn-Tucker conditions, different household collection decisions were explained. According to the model, the marginal products from collection in VWL and NF are equal for certain household groups engaged in both activities. When the shadow price of collection is greater than the price of fuelwood times the marginal utility of cash income, households tends to purchase fuel. The higher opportunity cost of labor leads to reduced collection of forest resources.

Tachibana et al., (2001) presented a dynamic model of agricultural intensification and tested its implications using commune level data in the northern hill region of Vietnam. The results suggested that the choice between intensification and extensification is relevant in hilly areas with limited flat land and sloped upland and that strengthened land rights particularly that on upland, tend to deter deforestation. The results of the comparative statistics are given in the Table 6.1.
Table 6.1. Theoretical relationships between exogenous and endogenous variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( L^a_t )</th>
<th>( S^b )</th>
<th>( T^{*c} )</th>
<th>( D^{*d} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_i ): Production efficiency in lowland farming</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( T_i ): Lowland farm area per capita</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( P ): Market price of upland products</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>( a ): Cost parameter of forest clearance</td>
<td>+</td>
<td>-</td>
<td>(i)</td>
<td>-</td>
</tr>
<tr>
<td>( c ): Insecurity index of upland property rights</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>(i)</td>
</tr>
<tr>
<td>( L ): Labor endowment</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

\( L^a_t \): labor input for upland farming  
\( S^b \): upland cropping intensity  
\( T^{*c} \): rotational shifting cultivation area at steady state  
\( D^{*d} \): forest area to be cleared at steady state  
(i): ambiguous  
Source: Tachibana et al. (2001).

The findings of the above study showed that the improvement of lowland production efficiency, \( E_i \), leads to a smaller upland cultivation area, and a lower deforestation rate at the steady state.

6.2 Empirical Model

Household decision making regarding forest resource extraction is governed by a set of variables including physical, personal and economic factors (see Bluffstone et al., 2001; Cavendish, 2000; Gunatilake, 1998; Godoy and Bawa, 1993; Godoy et al., 2000; Pattanayak and Sills, 2001; Ruiz Pérez and Byron, 1999 and Vedeld et al., 2004 for more details). Forest dependency is also associated with historical reasons (Cooms, 1995) and cultural aspects (Balèe, 1989). Therefore, the overall goal of the model is to identify and test the key factors which are believed to have an effect on forest dependency. Hence, individual hypotheses can be formed based on forest resource extraction by rural households in the periphery of natural forests. These hypotheses are identified in the discussion below.
6.2.1 Hypothetical Scenario Associated with the Forest Dependency Model

1. Because rural households depend primarily on agriculture, increased technical efficiency of farming may have effects on forest extraction (see Shively, 2001 and Tachibana et al., 2001 i.e., the effect of technical efficiency on labor allocation and commodity substitution). Higher technical efficiency in farming implies increasing output given the same input levels thereby increasing profits. Hence, an inverse relationship is assumed between technical efficiency of farming and dependency of forest resources among rural households.

2. Education is an important factor affecting the dependency on forest resource extraction. More education is assumed to be associated with access to more information which could lead to better employment opportunities and divert people from subsistence agriculture and forest extraction activities (Gunatilake, 1998, Vedeld et al., 2004). On the other hand, education and experience are major determinants of wage. Hence, it is hypothesized that there is an inverse relationship between education and forest resource extraction by households.

3. Microeconomic theory suggests that the effect of economic development on the sustainability of foraging depends on wealth and will produce complex results. As described by Godoy and Bawa (1993), wealthier households and villages tend to: a). extract fewer plants and animals, b). spend less time foraging and more time in non-forestry occupations, c). consume fewer wild plants and game, and d). use more domesticated animals and industrial substitutes. However, wealthier households and villages also use greater quantities of environmental resources (Cavendish, 2000). For instance, wealthy households could allow villagers easier access to modern technologies.
such as automobile to speed up forest gathering and firearms for hunting. Considering the local situation, where, modern technology (such as firearms for hunting) is banned in conservation forests, it is hypothesized that increased wealth has a negative impact on forest resource extraction.

4. When off-farm employment opportunities increase, households will have less interest and time available for foraging activities. Hence, it is assumed that a negative relationship exists between off-farm income and forest extraction activities.

5. Family labor is a key component in forest gathering. Given the subsistence nature of forest gathering, it is not economical to employ hired labor. Therefore, availability of family labor when family members are not completely involved in other activities such as agriculture contributes to increased forest dependency.

6. Due to diversity and complexity of tropical forests, accumulated forest knowledge (experience in the collection of forest goods) affects the household’s collection ability. Households with greater knowledge of forest and forest products have a comparative advantage over less knowledgeable households. Therefore, a positive relationship is assumed between forest dependency and accumulated forest knowledge.

7. Forest gathering is done by both males and females (Wickramasinghe et al., 1996 and Ruiz Pérez et al., 2002). In the study areas, fuelwood gathering is mainly done by females, while other NTFPs are mainly collected by male households though there are exceptions. The effect of the male:female ratio on forest dependency is dependent upon the types of forest goods gathered. For example, if fuelwood is the major item for forest gathering, then an inverse relationship is assumed between higher male:female ratio and forest dependency. If larger income shares are gained from forest products which male
households specialize in collecting (i.e., hunting, tapping of palm trees etc.) then the higher male:female ratio would lead to increased forest dependency. However, due to the complex nature of gender allocation in forest good collection, the overall effect may be ambiguous (see Hasalkar et al., 2004 and Morris et al., 2004 for more details).

8. Income diversification is a strategy that rural households practice for different reasons (see Reardon et al., 2000; Huggblade et al., 1989; Valdivia, et al., 1996 and Vedeld et al., 2004). Given the household's perception on the allocation of time and labor for productive income sources, an inverse relationship between the diversification index and forest gathering is hypothesized (However, this assumption doesn't hold in a situation where there is no diversification of household income and the family is completely involved in agriculture or a single income source).

9. If distance to the forest is too far from the village, households may show less interest in foraging (Heltberg et al., 2000). Greater distances to forests imply higher opportunity cost of time for extraction activities. Hence, a negative relationship is hypothesized between distance to the forest and extraction.

10. Tropical forests have contributed to the well being of local people by providing a form of natural insurance. Pattanayak and Sills (2001) conceptualized a microeconomic model relating agricultural risk to NTFPs in the Brazilian Amazon and found that households rely on forests to mitigate agricultural risk. Hence, a positive relationship between agricultural risk and forest dependency is conjectured.

11. The availability of credit for farming activities may have an effect on household dependency on forest resources. If the likelihood of obtaining credit increases, farmers would be more interested in investing in farming activities. In developing
countries, access to credit is one of the major limiting factors in farm activities. For different parts of the world, researchers (Gardner, 1969; Hussain and Young, 1986; Sahota, 1968) have found similar results. Therefore, it is hypothesized that greater access to credit has an inverse effect on the extraction of forest resources.

12. The level of debt is often perceived as an economic factor affecting forest dependency decisions. The familiar argument is that operations with a high debt service load (e.g., land mortgage) are often forced to reduce farming activities and spend more time in off-farm work and on foraging. Therefore, an overall positive relationship between level of debt and effort on extraction would be expected.

Although, all of the above relationships are important to fully understand the dependency of forest resources, it is not easy to measure some of the variables in a cross sectional survey. Agricultural risk can be measured as a coefficient of variation in prices or yields of major crops. However, time series data are needed to estimate price and yield risk. Therefore, variables representing agricultural risk were not included in the empirical model. Also, due to the limited availability of credit to rural households and the difficulties in measuring debt levels, variables credit and debt were also excluded in the final model (6.1).

The econometric estimation strategy requires a dependent variable that measures forest dependency. Literature indicates, forest collection labor as one way to measure forest dependency (see Bluffstone et al., 2001 and Pattanayak and Sills, 2001). However, there are difficulties in measuring time allocation for extraction. On the other hand, the number of trips does not necessarily reflect forest dependency. Forest dependency could also be defined in relative terms (i.e., forest income as a proportion of total income) or
could also be measured as a dummy variable, but none of these reflect the magnitude of forest goods extraction. The economic value of extracted forest goods is considered as a better indicator in reflecting forest dependency, hence taken as a dependent variables in the empirical model.

The model can be mathematically represented as:

\[ Y_{if} = \beta_0 + \beta_1(X_{1i}) + \beta_2(X_{2i}) + \beta_3(X_{3i}) + \beta_4(X_{4i}) + \beta_5(X_{5i}) + \beta_6(X_{6i}) + \beta_7(X_{7i}) + \beta_8(X_{8i}) + \beta_9(X_{9i}) + \varepsilon_i \]

Where:

- \( Y_{if} \) is the economic value of extracted forest goods in Sri Lankan rupees
- \( X_{1i} \) is technical efficiency in farming (Effi) derived from translog production function
- \( X_{2i} \) is formal education (Edu) of household head (1 if received secondary education or otherwise zero)
- \( X_{3i} \) is off-farm income (Oinc) in rupees
- \( X_{4i} \) is family labor (Flabor) measured by the number of productive members in the family
- \( X_{5i} \) is accumulated forest knowledge (Exp) measured in number of years of experience in gathering of forest goods
- \( X_{6i} \) is male to female ratio (Mfratio)
- \( X_{7i} \) is household wealth (Wealth) measured by the value of the selected goods (i.e., livestock, tractors, bicycles, radios, equipments used with animals)
- \( X_{8i} \) is distance to the forest (Dis) from home in kilometers
- \( X_{9i} \) is diversification index (Dindex) measured using inverse Simpson index of diversification
\( \beta_i \)'s are unknown parameters to be estimated

\( \varepsilon_i \) is the error term

The variable associated with diversification can be constructed by the inverse Simpson index of diversity (Hill, 1973).

\[
\text{Index of diversity} = 1 / \sum_{i=1}^{N} P_i^2
\]

Where:

\( N \) = number of different income sources

\( P_i \) = household income generated by activity \( i \)

See Valdivia et al. (1996) for an application of this index.

### 6.2.2 Probit Estimation

Forest dependency can also be estimated from data where the dependent variable is a zero-one variable. This implies that if households depend on forest resource extraction, then a one is used or otherwise zero. The application of ordinary least squares to data with a binary dependent variable leads to a heteroskedastic error structure and inefficient parameter estimates (Goldberger, 1964, Pindyck and Rubinfeld, 1983). Furthermore, due to a non-normal error structure, classical hypothesis tests such as t-test are no longer appropriate (Shakya and Flinn, 1985). Therefore, the alternative is to use probability models, which allow the fitted values to lie within the 0-1 interval. The behavioral model accounts for a dichotomous dependent variable such as depending or not depending on forest resource extraction. A general behavioral model can be stated as follows:
A utility index $I$ is defined for individual $i$ as $I_i = x_i' \beta$. The choice probabilities lie between zero and one and the index $I$ is in the range $(-\infty, +\infty)$. This can be translated to a 0-1 range by the use of the cumulative distribution function such that
\[ \Pr(y_i = 1) = P_i = F(I_i) = F(x_i' \beta). \]

The probit model, which is based on the cumulative normal probability function, can be written as follows:
\[ F(x_i' \beta) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{I_i} \exp\left(-\frac{t^2}{2}\right) dt. \]
where:
- $t_i$ = random variable with mean zero and unit variance.

The predicted probabilities are computed as:
\[ \hat{y}_i = \hat{P}_i = F(x_i' \hat{\beta}) \hat{\beta}_k, \]

Similarly, the logit model is based on the cumulative logistic probability function and can be specified as follows:
\[ F(x_i' \beta) = \frac{1}{1 + \exp(-x_i')} \]

The coefficients tell the effect of a change in the independent variable on the utility index. The impact of a unit increase in an explanatory variable on the choice probability can be obtained by estimating the marginal effects as follows:
\[ \frac{\partial \hat{P}_i}{\partial x_{kt}} = f(x_i' \hat{\beta}) \hat{\beta}_k \text{ where } f(\cdot) \text{ is the normal density function.} \]
6.2.3 Possible Problems Associated with the Empirical Model

A multiple regression model can be generally represented by the following equation

\[ Y_i = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_k x_{ki} + \epsilon \]

where \( \epsilon \) denotes the stochastic disturbance and \( \beta_i \) are the parameters to be estimated, where \( i = 0, \ldots, k \).

The proper use of this model is dependent upon meeting the following assumptions.

a. \( \epsilon \) is normally distributed with zero mean, i.e., \( E[\epsilon_i] = 0 \)

b. The disturbance term has constant variance, i.e., \( E[\epsilon_i^2] = \sigma^2 \)

c. The disturbance term is uncorrelated, i.e., \( E[\epsilon_i \epsilon_j] = 0, (i = j) \)

d. The number of observations exceed the number of coefficients to be estimated

e. No exact linear relationship exists between any two of the explanatory variables

f. Explanatory variables are non-stochastic with values fixed in repeated samples.

When one or more of the assumptions are violated, the results obtained using the model can lead to estimation bias. The given condition in the second assumption is known as homoskedasticity and when this condition is not met, the result is heteroskedasticity, which requires correction. The third assumption requires that the error be non-autoregressive and together with assumption two, it requires that error be independent. If the present error term is related to either past error or future error this leads to serial correlation.

Another possible and frequent problem in multiple linear regression is the violation of the fifth assumption i.e. multicollinearity. This occurs when explanatory
variables are correlated or a linear combination exists among explanatory variables. If extreme multicollinearity exists, the system of equations cannot be uniquely solved. For lesser degrees of multicollinearity, parameter significance/insignificance can present difficulties in hypothesis testing.

Kmenta (1997) and Green (2000) describe a few situations where the specification errors of a multiple regression model could occur. These are:

i. Omission of a relevant explanatory variable

ii. Disregard of a qualitative change in an explanatory variable

iii. Inclusion of an irrelevant explanatory variable

iv. Incorrect mathematical form of the regression equation

v. Incorrect specification of the way in which the disturbance enters the equation

Possible, heteroskedasticity and, multicollinearity problems were tested in the data analysis stage and necessary steps were taken to overcome the problems described by Greene (2000).
6.3 Results and Discussion

Ordinary Least Square (OLS) regression was performed to check for data problems (Green, 2000). Multicollinearity was found not to be a major problem in the data set (i.e., according to correlation matrix of coefficients, highest correlation was found between efficiency and wealth which is 0.34). However, heteroskedasticity was widely detected in the data (Appendix H). Therefore, OLS results are biased with low $R^2$ values. Hence, Feasible Generalized Least Square (FGLS) estimation was performed under three sub-categories. First, estimation was performed by using all forest goods including firewood (Table 6.2). Then, separate analysis was followed for all categories of NTFP (Table 6.3) and for fuelwood (Table 6.4). Heteroskedasticity was not a problem in the FGLS model (Appendix H) although some lower order heteroskedasticity was visible for the Dunhinda reserve case. The FGLS $R^2$ statistics were high in most cases. However, this is a weighted statistic and not comparable with the OLS $R^2$ value. Appendix I shows the analytical results of using forest dependency as a ratio of forest income to total income. Estimation of probit analysis is given in Table 6.5.

6.3.1 Estimation of Forest Dependency Model (NTFP and Fuelwood)

Estimation for NTFP and fuelwood categories showed that the index of technical efficiency ($Eff_i$) had a negative and statistically significant relationship with forest dependency. Technical efficiency decreases costs and increases profits hence efficient farmers may tend to less depend on forest resources. Increasing technical efficiency by 0.1 unit will decrease total forest income by 395, 847, 810, and 593 rupees/year respectively for the households living in investigated forest margins. Appendix J shows
the relationship between technical efficiency and forest income. Also agricultural income and household total income showed positive relationship with technical efficiency in agriculture (see Appendix K and L).

Formal education (Edu) had a negative and significant effect for the Galagodabedda and Bibilehela–Welanvita forest reserves. Formal education may be an effective variable to capture environmental awareness of farmers who are basically literate. For these two forest reserves, households who had secondary level of education showed reduction of forest dependency by 1203 and 916 rupees/year respectively. For Dunhinda and Kithulanahela reserves, Edu showed an unexpected positive effect however the estimated coefficients were not statistically significant.

Off-farm income (Oinc) had a negative and statistically significant relationship except for the Galagodabedda forest reserve. Increasing off-farm income by 1000 rupees/year implied a reduction of forest dependency by 150, 60 and 170 rupees/year for the Dunhinda, Kithulanahela and Bibilehela-Welanvita forest reserves respectively.

Family labor (Flabor) and experience in foraging (Expe) were not statistically significant in all four cases.

The male:female ratio (Mfratio) was positive in all sites however significant only for the Kithulanahela and Galagodabedda reserves. Increasing Mfratio by 1 unit produced an increase in forest dependency by 298 and 1771 rupees/year for the Kithulanahela and Bibilehela-Welanvita forest reserves respectively. Forest extraction is a male dominant activity in these two forest reserves.

Household wealth had a negative and significant relationship with forest dependency except for the Bibilehela–Welanvita reserve. Possession of additional wealth
of 1000 rupees had a decreasing effect of forest dependency by 70, 50, and 80 rupees/year for the Dunhind, Kithulanahela and Galagodabedda forest reserves respectively.

The variable distance (Dis) showed an expected negative sign for all investigated forest reserves but was not significant for any of the forest reserves.

The index of diversification (Dindex) had a negative and significant effect on forest dependency except for the Galagodabedda site. Increasing Dindex by 1 unit implied a decreasing effect on forest dependency by 1677, 1082, and 857 rupees/year for the Dunhind, Kithulanahela and Bibilehela-Welanvita forest reserves respectively. This indicates that households with more diverse income sources are less dependent on forest resource extraction (see Caviglia and Sills, 2005 for further evidences from Brazilian Amazon on this issue). Appendix M shows the relationship between income diversification and forest income. Results further showed (Appendix N) the positive relationship between diversification and household total income (see Vedeld et al., 2004 for contradictory views).
Table 6.2. Estimation on forest dependency for all forest product category.

<table>
<thead>
<tr>
<th></th>
<th>Dunhinda</th>
<th>Kithulanahela</th>
<th>Galagobedda</th>
<th>Bibilchla-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated</td>
<td>Std. error</td>
<td>t-ratio</td>
<td>Estimated</td>
</tr>
<tr>
<td>Effi</td>
<td>-3954.6</td>
<td>1920</td>
<td>-2.06*</td>
<td>-8473</td>
</tr>
<tr>
<td>Edu</td>
<td>261.81</td>
<td>388.8</td>
<td>0.67</td>
<td>251.36</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.15</td>
<td>0.02</td>
<td>-7.65*</td>
<td>-0.06</td>
</tr>
<tr>
<td>Flabor</td>
<td>-126.23</td>
<td>113.5</td>
<td>-1.11</td>
<td>87.24</td>
</tr>
<tr>
<td>Exp</td>
<td>-30.97</td>
<td>22.32</td>
<td>-1.39</td>
<td>22.88</td>
</tr>
<tr>
<td>Mfratio</td>
<td>14.51</td>
<td>261.9</td>
<td>0.06</td>
<td>297.74</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.07</td>
<td>0.03</td>
<td>-2.39*</td>
<td>-0.05</td>
</tr>
<tr>
<td>Dis</td>
<td>-920.61</td>
<td>744.0</td>
<td>-1.24</td>
<td>-1462</td>
</tr>
<tr>
<td>Dindex</td>
<td>-1677.0</td>
<td>594.5</td>
<td>-2.82*</td>
<td>-1082.5</td>
</tr>
<tr>
<td>Wt</td>
<td>20493</td>
<td>1771</td>
<td>11.57</td>
<td>14436</td>
</tr>
<tr>
<td>R²</td>
<td>0.92</td>
<td></td>
<td></td>
<td>0.93</td>
</tr>
<tr>
<td>adjusted</td>
<td>(0.64)</td>
<td></td>
<td></td>
<td>(0.66)</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
OLS R² adjusted values are in parentheses
Estimation results (NTFP category) showed that Effi had a negative and significant effect on dependency for NTFP except for the Bibilehela–Welanvita forest reserve. Increasing technical efficiency by 0.1 unit showed a reduction in NTFP dependency by 449, 2066, and 1682 rupees/year for the Dunhinda, Kithulanahela, and Galagodabedda forest reserves respectively.

The variable Edu was negative and showed a significant effect only for the Galagodabedda forest reserve. Having secondary education showed a reduction in NTFP of 2003 rupees/year for this forest reserve. The effect of education on forest dependency may have been complicated by the unemployment among educated households hence causing unexpected results.

For Oinc, the results were negative and significant for the Dunhinda and Kithulanahela reserves. Accordingly, increasing Oinc by 1000 rupees/year produced a reduction of NTFP dependency by 270 and 70 rupees/year respectively for the above two reserves. Although Oinc was negative for the Galagodabedda and Bibilehela-Welanvita forest reserves, these estimated coefficients were statistically insignificant.

The variable Flabor had a positive and significant effect on NTFP dependency for all reserves however was significant only for the Kithulanahela forest reserve. Increasing Flabor by 1 unit implied a reduction of NTFP dependency by 1241 rupees/year for the Kithulanahela reserve.

The Mfratio was positive and significant for the Dunhinda and Galagodabedda forest reserves while it was not significant for other reserves. Increasing Mfratio by 1 unit showed an increase in NTFP dependency by 377 and 3503 rupees/year for the Dunhinda
and Galagodabedda reserves. A positive and significant Mfratio indicates that extraction is male dominant activity. Major portion of NTFP income gained from bush meat hence the reason for male dominant behavior is due to the skills men possess in hunting. Wealth had a negative and significant effect on NTFP dependency for the Kithulanahela and Galagodabedda reserves. Accordingly, possessing additional wealth valuing 1000 rupees produced a decreasing effect of NTFP dependency by 180 and 170 rupees/year for these two forest areas.

Variable distance showed a negative effect on NTFP dependency only for the Dunhindha and Kithulanahela reserves. For other reserves, it showed a positive effect. However, variable Dis was not significant for any of the forest reserves.

The variable Dindex implied a negative effect for Dunhindha and Kithulanahela while it was positive for other reserves. However, Dindex was not significant for any of the forest reserves.
Table 6.3. Estimation on forest dependency for the NTFP only.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulanahele</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
<td>t-ratio</td>
<td>Estimated coefficient</td>
</tr>
<tr>
<td>Effi</td>
<td>-4488.7</td>
<td>10321</td>
<td>-4.35*</td>
<td>-4.35*</td>
</tr>
<tr>
<td>Edu</td>
<td>-136.5</td>
<td>209.7</td>
<td>-0.65</td>
<td>-0.65</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.27</td>
<td>0.01</td>
<td>-2.67*</td>
<td>-2.67*</td>
</tr>
<tr>
<td>Flabor</td>
<td>180.28</td>
<td>92.63</td>
<td>1.95</td>
<td>1.95</td>
</tr>
<tr>
<td>Exp</td>
<td>35.13</td>
<td>10.29</td>
<td>3.42*</td>
<td>3.42*</td>
</tr>
<tr>
<td>Mfratio</td>
<td>376.77</td>
<td>174.3</td>
<td>2.16*</td>
<td>2.16*</td>
</tr>
<tr>
<td>Wealth</td>
<td>0.2(-02)</td>
<td>0.02</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Dis</td>
<td>-261.91</td>
<td>389.3</td>
<td>-0.67</td>
<td>-0.67</td>
</tr>
<tr>
<td>Dindex</td>
<td>-446.12</td>
<td>240.8</td>
<td>1.85</td>
<td>1.85</td>
</tr>
<tr>
<td>Wt</td>
<td>2610.3</td>
<td>912.1</td>
<td>2.86*</td>
<td>2.86*</td>
</tr>
<tr>
<td>R²</td>
<td>0.68</td>
<td>0.69</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

* significant at 0.05 level

OLS R² adjusted values are in parentheses
6.3.3 Estimation of Forest Dependency Model (Fuelwood)

In the fuelwood dependency model, variable Effi had a negative and significant effect for the Dunhinda and Kithulanahela reserves. Increasing technical efficiency by 0.1 unit produced a reduction in fuelwood dependency by 746 and 349 rupees/year for the above two reserves respectively. For other forest reserves, variable Effi showed a decreasing effect on fuelwood dependency however estimated coefficients were not statistically significant.

The variable Edu had an unexpected positive and significant result for the Dunhinda reserve however, it was not significant for the other forest reserves. The effect of education on forest dependency may have overshadowed by the unemployment among educated households hence caused unexpected results in variable related to Edu (see Gunatilake, 1998 for further evidence related to this issue).

The variable Oinc had a negative and significant result for the Dunhinda and Kithulanahela reserves, which indicates that households receive income through off-farm employment sources extract less fuelwood. An increase in Oinc by 1000 rupees/year implied a reduction in fuelwood dependency by 50 and 20 rupees/year for these two reserves respectively. Though Oinc showed a negative effect on fuelwood dependency for the other two reserves, the results were not statistically significant.

The variable Flabor showed a positive effect on fuelwood dependency for the Dunhinda and Kithulanahela reserves however the results were not statistically significant. For other reserves, flabor had a negative effect but these estimated coefficients were not statistically significant.
The variable Exp showed a positive effect for Dunhinda, Kithulanahela and Galagodabedda reserves but significant (at 0.1 level) only for Dunhinda. Variable Exp had an unexpected negative and significant effect on fuelwood dependency for the Bibilehela–Welanvita reserve. A possible reason for this result may be due to the correlation between variable exp and age. More experienced households tend to be the older households and these households may collect less fuelwood compared to younger households.

The Mfratio had a negative and significant effect for the Dunhinda and Kithulanahela forest areas. Increasing the Mfratio by one unit showed a decreasing effect on fuelwood dependency by 665 and 129 rupees/year for these two reserves respectively. Fuelwood collection may be a female specialized activity in these areas. However, variable Mfratio showed a positive and significant effect for the Bibilehela–Welanvita reserve. Accordingly, increase of Mfratio by one unit showed increase of fuelwood dependency by 1580 rupees/year for this reserve. Fuelwood collection seems to be a male dominant activity for Bibilehela–Welanvita reserve. These ambiguous results related to Mfratio may be due to the complex nature of gender involvement in forest good extraction as explained in the hypothesis.

The variable wealth exhibited a negative and significant effect on fuelwood dependency except for the Galagodabedda forest reserve. Accordingly, possession of additional wealth with a value 1000 rupees showed that reductions of fuelwood dependency by 60, 30, and 90 rupees/year for the Dunhinda, Kithulanahela, and Galagodabedda reserves respectively.
The variable distance exhibited an unexpected positive and significant effect on fuelwood dependency for the Dunhinda and Glagoadbedda reserves. For these two reserves, an increase in distance by 1 kilometer produced an increase in fuelwood dependency by 1205 and 2490 rupees/year respectively. One possible explanation may be that for greater distances, households collect more fuelwood in order to minimize the number of trips for collection hence, perhaps households over estimate fuelwood collection. Also, distance is not easily measured hence, its accuracy may be questionable in a field survey.

The variable Dindex was negative and significant except for the Galagodabedda reserve. Households with more diversified income sources tend to depend less on fuelwood collection. Accordingly, an increase in the index of diversification by one unit showed a reduction in fuelwood dependency by 1494, 482, and 1835 rupees/year for Dunhinda, Kithulanahela, and Galagodabedda reserves respectively.
Table 6.4. Estimation on forest dependency for the fuelwood.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulananahela</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
<td>t-ratio</td>
<td>Estimated coefficient</td>
</tr>
<tr>
<td>Effi</td>
<td>-7460.1</td>
<td>1756</td>
<td>-4.25*</td>
<td>-3488.1</td>
</tr>
<tr>
<td>Edu</td>
<td>888.66</td>
<td>246.1</td>
<td>3.61*</td>
<td>22.71</td>
</tr>
<tr>
<td>Oine</td>
<td>-0.05</td>
<td>0.02</td>
<td>-3.01*</td>
<td>-0.02</td>
</tr>
<tr>
<td>Flabor</td>
<td>179.88</td>
<td>113.6</td>
<td>1.58</td>
<td>113.94</td>
</tr>
<tr>
<td>Exp</td>
<td>46.03</td>
<td>23.64</td>
<td>1.95</td>
<td>0.73</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-665.16</td>
<td>210.1</td>
<td>-3.17*</td>
<td>-129.37</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.06</td>
<td>0.02</td>
<td>-2.56*</td>
<td>-0.03</td>
</tr>
<tr>
<td>Dis</td>
<td>1205.1</td>
<td>481.2</td>
<td>2.50*</td>
<td>407.7</td>
</tr>
<tr>
<td>Dindex</td>
<td>-1494.0</td>
<td>391.1</td>
<td>-3.82*</td>
<td>-482.15</td>
</tr>
<tr>
<td>Wt</td>
<td>1388.1</td>
<td>1414</td>
<td>9.82*</td>
<td>6306.2</td>
</tr>
<tr>
<td>R²</td>
<td>0.88</td>
<td>0.99</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>adjusted</td>
<td>(0.53)</td>
<td>(0.55)</td>
<td></td>
<td>(0.19)</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
OLS R² adjusted values are in parentheses
6.3.4 Estimation of Forest Dependency Model (Probit Analysis)

The estimated Probit model produced mixed results. The coefficients indicate the effect of change in the dependent variable on the utility index (Table 6.5). Variable Effi had a negative and significant effect for all forest reserves. The variable Edu, was negative and insignificant for all reserves. Variable Flabor had a positive and significant effect only for the Kithulanahela reserve while it showed an unexpected negative and significant effect for the Dunhinda reserve. As shown in summary statistics, allocation of family labor for farming is higher in Dunhinda. The unexpected negative sign may be due to the diversion of family labor for farming in larger families. Exp had a positive and significant effect for all reserves except for Dunhinda. The Mfratio was insignificant in all forest reserves except for Galagodabedda. Wealth showed an insignificant effect for all reserves. Distance was negative and significant for the Dunhinda reserve while it showed an unexpected positive and significant effect for the Bibilehela-Welanvita reserve. The unexpected positive sign may be due to measurement error of the distance between home to the forest. The variable Dindex indicated a negative and significant effect in all reserves except Galagodabedda. The impact of a unit increase in an explanatory variable on the choice probability was obtained by estimating the marginal effects. Results are shown in Appendix 0.
Table 6.5. Probit estimation of the determinants of forest dependency.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda Estimated coefficient</th>
<th>Std. error</th>
<th>t-ratio</th>
<th>Kithulamahela Estimated coefficient</th>
<th>Std. error</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effi</td>
<td>-3.64</td>
<td>1.11</td>
<td>-3.28*</td>
<td>-3.81</td>
<td>1.52</td>
<td>-2.51*</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.22</td>
<td>0.17</td>
<td>-1.29</td>
<td>-0.13</td>
<td>0.28</td>
<td>-0.47</td>
</tr>
<tr>
<td>Oinc</td>
<td>0.19(-04)</td>
<td>0.14(-04)</td>
<td>1.47</td>
<td>0.14(-04)</td>
<td>0.15(-04)</td>
<td>0.89</td>
</tr>
<tr>
<td>Flabor</td>
<td>-0.24</td>
<td>0.98(-01)</td>
<td>-2.43*</td>
<td>0.38</td>
<td>0.15</td>
<td>2.45*</td>
</tr>
<tr>
<td>Exp</td>
<td>-0.24(-01)</td>
<td>0.14(-01)</td>
<td>-1.69</td>
<td>0.45(-01)</td>
<td>0.13(-01)</td>
<td>3.46*</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.24</td>
<td>0.15</td>
<td>-1.55</td>
<td>-0.93(-01)</td>
<td>0.16</td>
<td>-0.58</td>
</tr>
<tr>
<td>Wealth</td>
<td>0.13(-04)</td>
<td>0.13(-04)</td>
<td>1.05</td>
<td>-0.34(-04)</td>
<td>0.29(-04)</td>
<td>-1.15</td>
</tr>
<tr>
<td>Dis</td>
<td>-0.97</td>
<td>0.38</td>
<td>-2.54*</td>
<td>-1.99</td>
<td>1.23</td>
<td>-1.62</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.75</td>
<td>0.24</td>
<td>-3.15*</td>
<td>-0.86</td>
<td>0.33</td>
<td>-2.64*</td>
</tr>
<tr>
<td>Constant</td>
<td>2.15</td>
<td>1.11</td>
<td>1.94</td>
<td>5.34</td>
<td>1.47</td>
<td>3.63*</td>
</tr>
</tbody>
</table>

* significant at 0.05 level

Table 6.5. (Continued) Probit estimation of the determinants of forest dependency.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Galagodabedda Estimated coefficient</th>
<th>Std. error</th>
<th>t-ratio</th>
<th>Bibileheia-Welanvita Estimated coefficient</th>
<th>Std. error</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effi</td>
<td>-3.44</td>
<td>1.28</td>
<td>-2.69*</td>
<td>-5.35</td>
<td>1.66</td>
<td>-3.23*</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.34</td>
<td>0.24</td>
<td>-1.43</td>
<td>-0.34</td>
<td>0.38</td>
<td>-0.90</td>
</tr>
<tr>
<td>Oinc</td>
<td>0.34(-06)</td>
<td>0.11(-04)</td>
<td>0.03</td>
<td>-0.24(-04)</td>
<td>0.13</td>
<td>-1.79</td>
</tr>
<tr>
<td>Flabor</td>
<td>0.27</td>
<td>0.16</td>
<td>1.67</td>
<td>0.18</td>
<td>0.15</td>
<td>1.17</td>
</tr>
<tr>
<td>Exp</td>
<td>0.32(-01)</td>
<td>0.14(-01)</td>
<td>2.39*</td>
<td>0.89(-01)</td>
<td>0.33(-01)</td>
<td>2.68*</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.38</td>
<td>0.17</td>
<td>-2.18*</td>
<td>-0.18</td>
<td>0.24</td>
<td>-0.76</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.24(-04)</td>
<td>0.15(-04)</td>
<td>-1.57</td>
<td>0.36(-04)</td>
<td>0.22(-04)</td>
<td>1.68</td>
</tr>
<tr>
<td>Dis</td>
<td>0.74(-01)</td>
<td>0.81</td>
<td>0.09</td>
<td>5.74</td>
<td>1.82</td>
<td>3.15*</td>
</tr>
<tr>
<td>Dindex</td>
<td>0.34</td>
<td>0.35</td>
<td>0.98</td>
<td>-1.47</td>
<td>0.41</td>
<td>-3.55*</td>
</tr>
<tr>
<td>Constant</td>
<td>2.15</td>
<td>1.11</td>
<td>1.94</td>
<td>5.34</td>
<td>1.47</td>
<td>3.63*</td>
</tr>
</tbody>
</table>

* significant at 0.05 level

6.3.5 Economic Value of NTFP and Fuelwood to Rural Communities

Table 6.6 shows the economic value of NTFPs and fuelwood to rural households in the study sites. Due to the complexity in getting accurate information related to labor allocation for processing etc., calculation of net economic value was not done. Hence the values describe in the proceeding reflect the gross economic value of forest products (as processing is minimal for most NTFPs, a major difference between gross and net economic value of forest goods is not anticipated). Estimated mean annual per capita
economic values of NTFPs to the households for Dunhinda, Kithulanahela, Galagodabedda, and Bibilehela–Welanvita reserves were 2,324, 3,292, 3,074, and 764 rupees respectively. The mean annual per capita economic values of fuelwood to the households for the above forest reserves were 5,631, 2,528, 3,258, and 4,528 rupees/year respectively. For the Dunhinda and Bibilehela–Welanvita reserves, NTFPs account for 29 and 14 percent of total forest products respectively. NTFPs values for Kithulanahele and Galagodabedda account for approximately 50 percent from total forest products. Dominant NTFPs (i.e Wild meat, kithul products) contributed over 50 percent of the average annual per capita economic value from NTFPs to the households for the investigated forest margins.

The estimated total economic value of NTFPs for Dunhinda, Kithulanahela, Galagodabedda, and Bibilehela–Welanvita reserves were 378,811, 312,681, 292,012, and 70,330 rupees/year respectively. Estimated total economic value of fuelwood to the households for these reserves were 917,900, 240,160, 292,817, and 416,585 rupees/year respectively. Accordingly, the total economic values of all products in the above sites were 1,294,711, 528,644, 596,655, and 486,915 rupees/year respectively. The extent and pattern of dependency for the forest varies by community, depending on the nature, magnitude, and accessibility of forest resources (ADB, 2000). These estimated values were higher than those of the case studies done in wet zone forests (see Bogahawatta, 1998) and lower than the economic values of NTFPs extracted in several high productive forest reserves in Sri Lanka (see Gunatilake et al., 1993; Abeygunawardena, 1993, Abeygunawardena and Wickramasinghe, 1991; Bandaratilake, 1998).
Table 6.6. Economic value of NTFPs and fuelwood to households.

<table>
<thead>
<tr>
<th>Forest products</th>
<th>Dunhinda</th>
<th>Kithulanahela</th>
<th>Galagodabedda</th>
<th>Bibilehela–Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits</td>
<td>47.90</td>
<td>105.16</td>
<td>162.06</td>
<td>71.08</td>
</tr>
<tr>
<td>Vegetables</td>
<td>86.38</td>
<td>124.36</td>
<td>130.92</td>
<td>-</td>
</tr>
<tr>
<td>Yam</td>
<td>461.23</td>
<td>138.74</td>
<td>1.74</td>
<td>-</td>
</tr>
<tr>
<td>Mushroom</td>
<td>50.46</td>
<td>338.53</td>
<td>13.04</td>
<td>19.02</td>
</tr>
<tr>
<td>Spices</td>
<td>-</td>
<td>-</td>
<td>302.25</td>
<td>96.63</td>
</tr>
<tr>
<td>Wild Meat</td>
<td>778.75</td>
<td>994.74</td>
<td>934.78</td>
<td>369.56</td>
</tr>
<tr>
<td>Bee honey</td>
<td>-</td>
<td>65.79</td>
<td>3.26</td>
<td>99.45</td>
</tr>
<tr>
<td>Rattan</td>
<td>-</td>
<td>292.89</td>
<td>65.22</td>
<td>-</td>
</tr>
<tr>
<td>Medicinal plants</td>
<td>101.53</td>
<td>14.68</td>
<td>113.86</td>
<td>16.98</td>
</tr>
<tr>
<td>Grass</td>
<td>-</td>
<td>268.08</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thatching materials</td>
<td>-</td>
<td>19.73</td>
<td>102.44</td>
<td>14.95</td>
</tr>
<tr>
<td>Poles</td>
<td>557.21</td>
<td>106.32</td>
<td>67.39</td>
<td>76.76</td>
</tr>
<tr>
<td>Other products</td>
<td>240.82</td>
<td>822.36</td>
<td>1,177.22</td>
<td>-</td>
</tr>
<tr>
<td>(Caryota urensis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub total</td>
<td>2,323.99</td>
<td>3291.37</td>
<td>3,074.19</td>
<td>764.46</td>
</tr>
<tr>
<td>Firewood</td>
<td>5,631.28</td>
<td>2,528</td>
<td>3,257.61</td>
<td>4,528.09</td>
</tr>
<tr>
<td>Total average</td>
<td>7,955.27</td>
<td>5,819.37</td>
<td>6,331.84</td>
<td>5,292.55</td>
</tr>
</tbody>
</table>

6.3.6 Potential Benefits from Increasing Technical Efficiency

Table 6.7 shows additional income generated from increasing mean efficiency levels and the threshold efficiency levels needed to lessen forest dependency in different product categories. It is estimated that on average, a 0.1 increase in efficiency would increase agricultural income by 2,142–3,987 rupees/farm. Additionally, mean agricultural income would increase by 7,069–12,359 rupees/farm if farms were fully technically efficient. However, for the Dunhinda and Galagodabedda reserves, total forest income cannot be fully compensated even by achieving full efficiency. According to the analysis, mean threshold efficiency levels needed to reduce forest dependency for the Kithulanahela, and Bibilehela–Welanvita reserves were 0.93 and 0.82.
In technical terms, the mean threshold efficiency level needed to lessen NTFP dependency in Dunhinda, Kithulanahele, Galagodbedda, and Bibilehela-Welanvita forest reserves were 0.78, 0.83, 0.87, and 0.71 respectively. In the case of fuelwood, income is fully compensated by achieving threshold efficiency levels of 0.93, 0.81, 0.88, and 0.80 respectively in these forest reserves. Based on the economic value of forest products extracted from each forest reserve, it is estimated that increasing efficiency by 0.1 would reduce the opportunity cost of biodiversity conservation by 27, 46, 34, and 75 percents respectively in the forest under investigation (Table 6.8).
Table 6.7. Projected threshold efficiency levels needed to arrest forest dependency.

<table>
<thead>
<tr>
<th>Forest reserve</th>
<th>Mean annual farm income</th>
<th>Mean efficiency</th>
<th>Benefit of increasing efficiency (rupees/farm/year)</th>
<th>Threshold efficiency level needed to arrest forest dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.1 increase in efficiency</td>
<td>Full efficiency level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total forest dependency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NTFP dependency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fuelwood dependency</td>
</tr>
<tr>
<td>Dunhinda</td>
<td>14,352.36</td>
<td>0.67</td>
<td>2142.14</td>
<td>*</td>
</tr>
<tr>
<td>Kithulanahela</td>
<td>18,262.86</td>
<td>0.71</td>
<td>2572.09</td>
<td>7,459.48</td>
</tr>
<tr>
<td>Galagodabedda</td>
<td>15,949.73</td>
<td>0.73</td>
<td>2184.89</td>
<td>*</td>
</tr>
<tr>
<td>Bibilehela-Welani</td>
<td>27,509.62</td>
<td>0.69</td>
<td>3987.03</td>
<td>12,359.39</td>
</tr>
</tbody>
</table>

* denotes increased efficiency unable to compensate for forest income foregone (i.e., efficiency > 1)

** Estimated efficiency was statistically insignificant
Table 6.8. Estimated reduction of opportunity cost of biodiversity conservation.

<table>
<thead>
<tr>
<th>Forest reserve</th>
<th>Total revenue from agriculture due to increased efficiency by 0.1 (rupees)</th>
<th>Total revenues from forest products (rupees)</th>
<th>Share of forest products revenue compensated by additional revenue from a 0.1 increase in efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunhinda</td>
<td>349,146</td>
<td>1,294,711</td>
<td>26.9</td>
</tr>
<tr>
<td>Kithulanhela</td>
<td>244,340</td>
<td>528,644</td>
<td>46.2</td>
</tr>
<tr>
<td>Galagodabedda</td>
<td>200,928</td>
<td>596,655</td>
<td>33.7</td>
</tr>
<tr>
<td>Bibilehela-Welanvita</td>
<td>366,804</td>
<td>486,915</td>
<td>75.3</td>
</tr>
</tbody>
</table>
CHAPTER 7

SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Summary

Dependency on forest resources by rural households causes further depletion of natural forests. Minimizing forest dependency without affecting the welfare of dependent communities is one of the major challenges in conserving natural forests. Rural households living in forest margins primarily depend on agriculture and secondarily depend on other income sources including extraction of forest goods. Improvement in technical efficiency in agriculture is one way by which the agricultural capacity can be improved thereby improving the income of households. The study's major objective was an investigation of technical efficiency of agricultural farming in forest peripheries and its effect on rural household dependency on forest resource extraction.

Comparative statistics showed that the technical efficiency has a decreasing effect on labor allocation for forest resource extraction. Improving technical efficiency in agriculture may have two major effects, namely income effect and labor supply effect, on forest dependency. Due to income effects, households tend to substitute market commodities for forest commodities. Once agricultural production becomes profitable, then the opportunity cost of labor allocation for less productive sources such as forest gathering becomes high thereby decreasing labor allocation for forest resources.

The empirical analysis was based on the data collected from the peripheral villages of the five natural forest reserves in the district of Badulla in Sri Lanka. The study was done in two stages. In the first phase of the analysis, technical efficiency effects
for a cross-section of rural agricultural households in the periphery of the natural forest were modeled in terms of input variables in the production process. Various statistical hypotheses were tested for the smallholder farmers and their technical efficiencies of production are predicted. The empirical model of technical efficiency was based on the translog production function.

The statistical analysis confirmed the impossibility of pooling data due to site differences. This study's findings showed that the mean technical efficiency in agricultural farming for selected forest peripheries ranges between 0.67–0.73. The efficiency of individual farms lies between the efficiency range of 0.1–0.99. The results imply that there is potential for improving the technical efficiency of agricultural farming and thereby increasing farm revenues. Factors such as education, experience, extension, and the nutritional status of the household head are the primary determinants of inefficiency.

In the next step, the forest dependency model was assessed. Factors affecting forest dependency were assessed under three categories. First, total economic value of non-timber forest products including fuelwood was considered. Then, analysis was done for two separate subgroups of forest products namely, NTFPs and fuelwood. Further analysis included the probit estimation for forest dependency. Mixed results were obtained for this empirical estimation. Overall, the technical efficiency of agriculture, off-farm income, wealth and the diversification index showed statistically significant negative relationship with forest resource dependency.
7.2 Conclusions

Major conclusions from this research are noted below.

1. The existence of technical inefficiency in agricultural farms in forest peripheries and the consequent potential to improve technical efficiency in agriculture for forest margins were indicated by the research findings.

2. Factors such as agricultural extension, formal education, and the nutritional status of households were found to have statistically significant relationship in reducing technical inefficiency.

3. In the forest dependency model, factors such as technical efficiency in agriculture, off-farm income, household wealth and index of income diversification showed negative and statistically significant relationship in reducing forest dependency in most cases.

4. There is a trade-off between agriculture and forest income. Additional revenue gained by improvements in technical efficiency can partly meet the economic value of extracted forest goods. Therefore, increasing technical efficiency in agriculture may lessen forest dependency to a certain degree.

5. Technical efficiency improvement in agriculture is found to have a positive externality in conservation of forests.

6. Efficiency improvement in farming in forest margins should be considered as a policy option in protecting natural forests.

However, assumptions underlying household behavior must be considered before drawing conclusions. Most forest products are considered to be inferior goods in most economies. A notable exception is fuelwood, which is often essential to rural developing
economies. Consequently, an improvement in rural income may not reduce the dependency on fuelwood, at least in the short run, unless alternative energy sources are available at affordable prices.

Therefore other options which have the potential to minimize forest dependency should be explored. Income diversification is another effective strategy to enhance rural income by reducing forest dependency.

7.3 Limitations of the Study

Before drawing inferences for forest protection policy, it may be useful to summarize the study’s limitations. The statistically significant variables found in the estimation process support the household’s decision-making framework postulated in the theory and the empirical model.

Sri Lanka has diverse forest types hence there are variations in NTFPs available for households living in peripheries of different forest reserves. Also variations are expected in decision making by the communities living in various forest areas. This diversity and heterogeneity should be considered in interpreting the results in a broader context.

Adequate specification and measurement of independent variables is critical to the robustness of estimation results. Information error is expected in studies of this nature since the survey information is gathered from the interviewee’s recall. Hence, better measurement is needed.

Valuation of NTFPs and fuelwood was done using different market-based valuation techniques. An alternate technique to measure forest biodiversity is a non-market valuation method. However, due to various limitations and the lack of validity of
such techniques, because of the unfamiliarity of the respondent households, non-market valuation techniques were not used to measure the value of extracted forest products. Although maximum effort was made to minimize errors, possibility of making under- or over-valuation does exist. Slight errors in original estimates may cause large differences in the annual figures. Such errors were minimized by checking the internal consistency and re-checking the data in field visits. However, some errors and discrepancies are still unavoidable in a study of this nature.

Simultaneous equation estimation, although theoretically desirable, is not practical for this study because of many specification issues involving the measurement of endogenous and exogenous variables, and identification of equation system. However, the issue of simultaneity should be addressed in future studies by endogenizing technical efficiency in agriculture.

7.4. Policy Options

As discussed in section 1.1.2, it is clear that Sri Lanka’s forest policies have considered the need for conservation of natural forests given that existing forests are already heavily depleted. There are views that although Sri Lanka has a national forest policy and are implementing programs, there is a vast difference between what it has achieved and what is needed. Sri Lanka’s forest policies should address the needs of the dependent communities and their lifestyles.

One of the major problems of management of natural forests is the lack of adequate scientific direction coupled with policy enforcement (UNDP, 2004). Forestry sector research in Sri Lanka is very limited. The forest department has a small research division, which plays an insignificant role in the development of the forestry sector. In
addition, forest extension programs are designed as individual projects funded by donor agencies, without national level strategic planning (De Zoysa, 2001). Policy enforcement could probably be improved with the involvement of rural people in forest conservation and the involvement of local communities in effective conservation of protected forests.

Lack of scientific information in the policy formulation process may undermine forest policies. An example is the forest policy related to the intersectoral introduction on forest conservation. ADB (2000) identified the promotion of small-scale tea plantations as causing increased pressure on national forests. It further recommends comprehensive land-use planning and intersectoral policy coordination as a means to minimize the negative impacts of such externalities. However, there is an existence of competitive labor allocation between tea plantations and forest extraction. Hence, the promotion of tea plantations in forest peripheries produces positive externalities in biodiversity conservation.

Sri Lanka's forest policy does not address the ways to mitigate the higher opportunity cost of conservation. As Pushparajah (1986) highlighted, the opportunity cost of conservation of 10,000 hectares of forests was about 45 million rupees/year. Finding alternative ways of meeting these higher opportunity costs of conservation is also necessary for the successful implementation of forest conservation programs.

The results generated from this analysis are useful in designing alternative policies and strengthening existing policies for the forestry sector in Sri Lanka. However, this requires careful interpretation of results especially since this study is confined to few forest reserves in Badulla district of Sri Lanka and other forest reserves may have different socio-economic and natural environments. This study does show that under
present efficiency levels, households will continue to extract forest resources. Empirical evidence supports the potential to improve income from agriculture through technical efficiency. Compared to the measured technical efficiency levels (67, 71, 73, and 69 percent respectively), the efficiency gap which should be addressed by policy measures ranges from 2-14 percent for NTFPs categories and 10-26 percent for the fuelwood category.

Increasing technical efficiency in agriculture enables farmers to operate closer to frontier output level without expanding the agricultural frontier in forest peripheries. Hence, understanding the causes underlying technical inefficiency among farmers and the appropriate measures to minimize inefficiency can lead to the formation of important policies designed to protect the natural forests. However, any agricultural policy must be accompanied by policies to ensure that property rights for forests are intact without encroachment of agriculture on forestland.

Education is one of the keys to improving efficiency. Rural households should be made aware of the potential to improve profitability from using alternative input combinations. This will motivate farmers to achieve higher efficiency levels in farming activities. As Waxler (1994) highlighted, financial assistance to farmers in developing nations has often been unsuccessful. However, programs supporting self-sufficiency have been highly successful (Fragasso, 1995; Southgate, 1994; Waxler, 1994; Howell, 1993). Therefore, successful subsidization of agriculture would require the use of educational programs to teach farmers how to increase production using existing combination of inputs and therefore require substantial commitment. Without these education programs, efforts to increase efficiency of subsistence farming will most likely fail.
Information is a key factor in determining adaptation decisions. The problem of adoption is reduced to communicating information on the technology to the potential end users. Therefore, a rational farmer will adopt a superior technology when information is obtained about how it is used and obtained, and information suggests that actual results correspond to expected results. Hussain et al., (1994), Feder and Slade (1984), and Caviglia and Khan (2001) highlighted that information on new technology can increase the rate of adoption. As knowledge of the new technology increases, the rate of adoption is expected to increase. However, spread of information in rural areas of developing countries can be difficult. This may be the case for rural households living near forest peripheries in Sri Lanka. In such situations, agricultural extension plays an important role in diffusion of new technology.

Agricultural extension can also play a major role in reducing technical inefficiency. Availability, effectiveness and access to information and services are vital for rural agricultural development (Feder et al., 2004; Hussain and Perera, 2004; Kularatne, 1997). However, agricultural extension is not available on a regular basis for farming communities in the study sites. Hence, a restructuring of agricultural extension is an urgent need for improving efficiency in farming.

Outreach and extension efforts may need to be refocused to reach these rural farmers in order to improve their understanding of agricultural productivity and management of input use. Establishment of a cooperative extension system with closer integration of extension services offered by different institutions will increase the availability of assistance to rural communities. As shown by the results, increasing agricultural extension by one hour would reduce technical inefficiency in agriculture by
46, 62, 8, and 27 percent for the investigated forest margins, respectively. Accordingly, extension hours needed to increase technical efficiency by 0.1 require 0.22, 0.16, 1.25, and 0.37 hours of additional extension assistance to each household in the investigated forest peripheries, respectively. This type of policy change requires extra investment to strengthen agricultural extension. However, estimation of the actual cost to implement such a program is beyond the scope of this study.

Technical inefficiency was shown to be a decreasing function of the nutritional status of the household. Study findings also indicated that average calorie intake of rural households is considerably low. The recommended minimum average energy intake per day is 2,100 kilocalories, however estimated average daily energy intake in study sites is approximately 1633 kilocalories (according to a household income and expenditure survey completed in 2002 by the Department of Census and Statistics in Sri Lanka, per capita energy intake by rural poor households was 1768 kilocalories). Since farming in rural areas is labor intensive and the estimated production function results showed the significance of family labor in farm production, a balance diet is essential to maintain good health of the working force. The nutritional status of the households is important to increase labor productivity thereby increasing farm efficiency. Knowledge of the nutritional values of available foods and minimum daily requirements are important dietary information for households. According to the results, increasing daily energy intake by 100 kcal from the current mean levels would reduce technical inefficiency in agriculture by 17, 48, 21 and 19 percent for investigated forest margins respectively. Accordingly, energy needed to increase technical efficiency by 0.1 percent requires daily intake of 58.8, 20.8, 47.6, and 52.6 additional kilocalories to each household head in the
investigated forest peripheries respectively. Although rural households may be less willing to make dramatic changes to their current food consumption pattern, nonetheless, a well-balanced diet can lead to improvements in labor productivity without substantial increases in costs.

Increasing efficiency through these policies will help to reduce forest dependency by diverting labor resources from forest resource extraction. As Shively (2001) highlighted, technical change may increase effective labor demand, that is, the total amount of labor used on a hectare of land in a calendar year. Technical efficiency may be labor saving, and thereby reduce the amount of labor required per acre in a given season. Overtime, the additional profits gained through farming will increase cropping intensity and thereby increase the amount of labor used in farming. Agricultural intensification may lead to other environmental problems hence promotion of on-farm conservation programs is essential to ensure long-term sustainability of farming (see Napier et al., 1994).

Forestry sector studies in Sri Lanka (ADB, 2000) have shown that monthly cash income for rural households was inadequate and should be increased substantially to enable rural households to achieve a reasonable living standard. As pointed out in the analysis, increasing efficiency will help alleviate poverty to a certain degree and improve the household’s social standing. However, improved technical efficiency is not sufficient for rural households to achieve a threshold income level, which diminishes forest dependency. In pure technical terms, the additional income from increasing technical efficiency in agriculture may compensate for the loss of income or opportunity values.
from NTFPs and fuelwood. With the current understanding of rural household behavior, setting a minimum income goal to halt forest extraction is somewhat arbitrary at best.

The effect of household income on the consumption of forest products is small (Amachar et al., 1998) and some forest products are inferior goods and hence increases in income through technical efficiency will reduce demand for these forest resources. However, if the NTFPs have an inelastic demand, then increasing income may not affect its extraction. This may be the case for fuelwood extraction. Studies have shown that fuelwood has an inelastic demand, as it is essential for cooking purposes in rural areas. Given the limitation of alternative energy sources in rural markets, it is unlikely that rural households will immediately replace fuelwood by other energy sources even with an increase in income. In the short run, increasing technical efficiency in agriculture may not totally halt fuelwood collection. Though agricultural efficiency may be a necessary condition to reduce forest dependency but may not be a sufficient condition to totally stop forest resource extraction.

Along with policies for improving technical efficiency in agriculture, other options have to be explored. Results showed that off-farm income has a negative impact on dependency on forest resources. Creating employment opportunities for rural labor has two effects on decreasing forest dependency. First, lucrative income sources increase the opportunity costs for forest resource extraction, hence reduce labor used for forest gathering activities. Second, off-farm employment will also have a negative impact on forest dependency through the wealth effect.

Forest dependency among the households with more diversified income sources proved to be less. Introduction of diversified income sources is a vital and sustainable
strategy to arrest forest dependency. A household can diversify income through several sources such as agriculture, off-farm employment, homegardening, and livestock production. It was observed during field observations that households who maintain diversified homegardens with perennial cropping systems showed very limited dependency on forest resources. Rural households in the study sites predominantly used fuelwood as energy sources. Two major fuelwood sources are the homegardens and surrounding natural forests. Substitution between fuelwood from homegardens and natural forests is likely (see Amacher et al., 1993 and Cooke, 1998 for evidence of substitution between fuelwood and other energy sources). Therefore, investment to develop homegarden systems with perennial cropping systems may be vital in the long run for reducing forest dependency. Promotion of agroforestry systems is an effective option in meeting fuelwood needs of rural communities.

Income generation from other sectors such as agriculture and livestock farming could be improved with technical and financial assistance programs which upgrade current practices. Improving rural livestock farming could occur through the introduction of improved livestock breeds (cattle, goats, buffalo, and chickens), pasture management programs, etc. For the agricultural sector, introduction of crop diversification opportunities will provide rural households with better protection from the uncertainty associated with rural farming (see Barghouti et al., 2004 for multiplier effects from agricultural diversification). Crop diversification has a potential venue to increase farm profitability. This would require government services in research and extension, agricultural technology, crop varieties, capacity and effectiveness of institutions (for rural credit, information dissemination, subsidies, marketing), development of rural
infrastructure, etc. to ensure that producer incentives were maintained. This support would help transform less productive income generating systems to become more productive.

The Sri Lanka national forest policy drawn up in 1995 made references to exploitation, utilization, conservation, biodiversity and other elements that make up activities in the forestry sector. There are no direct references to poverty alleviation or social development. At the time this policy was formulated, there was no inference to poverty reduction from forestry policy. Reduction of poverty can be achieved through policies, which increase technical efficiency in agriculture and diversify household income sources. These policies will also have negative impacts on forest resource exploitation as shown by this study.

The majority of households in rural areas of the forest margins investigated depend on welfare benefits. The role of income subsidies for households who are in the poorest income group and its effect on forest resource extraction were not taken into consideration for this study. The primary reason for not considering the effects of welfare benefits is that the amount of subsidies is relatively constant across households and produces little behavioral change. It is also a political issue in Sri Lanka rather than an economic incentive. However, direct or indirect income transfers will assist rural low-income households in improving or at least maintaining their current nutritional consumption which this study has shown to have a positive impact on farming efficiency.

However, in order to secure the benefits from technical efficiency improvement and to encourage rural households to invest in farming and homegardening, improved access to productive resources such as land is necessary. Insecurity in land titles may
discourage rural households in forest margins from making long-term investments in land. As Scherr (2000) highlighted, property rights affect long-term agricultural productivity and incentives for conservation and investment in resource improvement. Therefore, policy makers should view land title issues as a necessary goal to capture benefits from efficiency.

Given the complex nature of protecting natural forests, other issues such as land rights, capacity and effectiveness of institutions (e.g., rural credit, information dissemination, subsidies, marketing etc.), and the development of rural infrastructure may influence rural household capacity to achieve a higher standard of life and should be explored. As highlighted by Dixon and Easter (1986), the management of natural resources should explicitly account for social, political, economic and institutional factors. A public and private partnership is needed to efficiently and effectively conserve natural forests. Hence, these results should be carefully considered when designing and implementing future forest conservation policies and programs.

Forest dependency is a very complex issue, which depends on the underlying behavior of rural households. Due to differences in the socio-economic environment and natural environment, variations can be seen in results generated from case studies done in different parts of the world. This diversity warrants future research in the area of forest dependency.
Figure A.1. Badulla district forest map.
APPENDIX B

LAND USE DATA IN BADULLA DISTRICT

Table B.1. Land use patterns in the divisional secretaries of Badulla district.

<table>
<thead>
<tr>
<th>Legend</th>
<th>Meegahakivula</th>
<th>Sorannathota</th>
<th>Passara</th>
<th>Haldummulla</th>
<th>District total in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban land</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>Agricultural land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homesteads</td>
<td>1340</td>
<td>1190</td>
<td>2350</td>
<td>2260</td>
<td>12.5</td>
</tr>
<tr>
<td>Tea</td>
<td>550</td>
<td>950</td>
<td>7630</td>
<td>4650</td>
<td>12.8</td>
</tr>
<tr>
<td>Rubber</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>600</td>
<td>0.3</td>
</tr>
<tr>
<td>Mixed tea and other perennial crops</td>
<td>-</td>
<td>70</td>
<td>20</td>
<td>240</td>
<td>0.2</td>
</tr>
<tr>
<td>Paddy</td>
<td>770</td>
<td>490</td>
<td>1020</td>
<td>620</td>
<td>7.1</td>
</tr>
<tr>
<td>Sparcely used crop land</td>
<td>5360</td>
<td>2810</td>
<td>7480</td>
<td>7680</td>
<td>29.9</td>
</tr>
<tr>
<td>Other crop land</td>
<td>-</td>
<td>20</td>
<td>50</td>
<td>1180</td>
<td>2.2</td>
</tr>
<tr>
<td>Forest land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dense forest</td>
<td>70</td>
<td>90</td>
<td>870</td>
<td>10660</td>
<td>7.4</td>
</tr>
<tr>
<td>Open forest</td>
<td>860</td>
<td>680</td>
<td>2640</td>
<td>5040</td>
<td>12.2</td>
</tr>
<tr>
<td>Forest plantations</td>
<td>10</td>
<td>20</td>
<td>1080</td>
<td>6740</td>
<td>4.6</td>
</tr>
<tr>
<td>Rangeland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrubland</td>
<td>-</td>
<td>350</td>
<td>1210</td>
<td>1120</td>
<td>5.1</td>
</tr>
<tr>
<td>Grassland</td>
<td>1030</td>
<td>120</td>
<td>2590</td>
<td>1390</td>
<td>3.6</td>
</tr>
<tr>
<td>Water</td>
<td>90</td>
<td>40</td>
<td>-</td>
<td>80</td>
<td>1.2</td>
</tr>
<tr>
<td>Barren land</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>630</td>
<td>0.6</td>
</tr>
<tr>
<td>Total area</td>
<td>10100</td>
<td>6830</td>
<td>26970</td>
<td>43070</td>
<td>100</td>
</tr>
</tbody>
</table>

*There are 14 divisional secretaries in Badulla district. This table only shows land use data in 4 divisional secretaries, which covers, investigated forest areas (i.e., Kithulanahela (Meegahakivula), Dunhinda (Sorannathota), Galagodabedda (Passara), Bibilehela-Welanvita (Haldummulla)
All area figures are given in hectares (1 ha = 2.47 acres
The deterministic frontier model is defined by:

\[ Y_i = f(x_i, \beta) \exp(-U_i) \quad i = 1, 2, \ldots, N \] F.1

Where \( Y_i \) represents the possible production level for the \( i \)th sample firm; \( f(x_i, \beta) \) is a suitable function (e.g., Cobb-Douglas or translog) of the vector, \( x_i \), of inputs for the \( i \)th firm and a vector, \( \beta \), of unknown parameters; \( U_i \) is a non-negative random variable associated with firm specific factors which contribute to the \( i \)th firm not attaining maximum efficiency of production; and \( N \) represents the number of firms involved in a cross-sectional survey of the industry.

The presence of the non-negative random variable, \( U_i \); in model (F.1) is associated with the technical inefficiency of the firm and implies that the random variable, \( \exp(-U_i) \), has values between zero and one. Thus it follows that the possible production, \( Y_i \), is bounded above by the non-stochastic (i.e., deterministic) quantity, \( f(x_i, \beta) \). Hence the model F.1 is referred to as a deterministic frontier production function. The inequality relationships:

\[ Y_i \leq f(x_i, \beta) \quad i = 1, 2, \ldots, N \] F.2

were first specified by Aigner and Chu (1968) in the context of a Cobb-Douglas model. It was suggested that the parameters of the model be estimated by applying linear or quadratic programming algorithms. Aigner and Chu (1968) suggested that chance-constrained programming could be applied to the inequality restrictions (F.2) so that
some output observations could be permitted to lie above the estimated frontier. Timmer (1971) explored this suggestion and obtained the so-called probabilistic frontier production functions, for which a small proportion of the observations is permitted to exceed the frontier. Although this feature was considered desirable because of the likely incidence of outlier observations, it obviously lacked any statistical or econometric rationale (Battese, 1992).

The frontier model (3.1) was first presented by Afriat (1972). Richmond (1974) further considered the model under the assumption that \( U_i \) had a distribution with parameters, \( r = n \) and \( \lambda = 1 \) (see Mood et al., 1974). Schmidt (1976) stated that the maximum-likelihood estimates for the \( \beta \) parameters of the model could be obtained by linear and quadratic programming techniques if the random variables had exponential or half normal distribution, respectively.

The technical efficiency of a given firm is defined to be the factor by which the level of production for the firm is less than its frontier output. Given the deterministic frontier model (3.1), the frontier output for the \( i^{th} \) firm is \( Y_i^* = f(x_i, \beta) \) and so the technical efficiency for the \( i^{th} \) firm, denoted by \( TE_i \), is:

\[
TE_i = Y_i / Y_i^* = f(x_i, \beta) \exp(-U_i) / f(x_i, \beta) = \exp(-U_i)
\]

Technical efficiencies for individual firms in the context of the deterministic frontier production function (3.1) are predicted by obtaining the ratio of the observed production values to the corresponding estimated frontier values. \( TE_i = Y_i / f(x_i, \hat{\beta}) \) where
\( \hat{\beta} \) is either the maximum likelihood estimator or the Corrected Ordinary Least Squares (COLS) estimator for \( \beta \).

If the \( U_i \) random variables of the deterministic frontier (F.1) have an exponential or half normal distribution, inference about the \( \beta \) parameters cannot be obtained from the maximum likelihood estimators because the well known regularity conditions (Theil, 1971) are not satisfied. Greene (1980) presented sufficient conditions for the distribution of the \( U_i \)'s for which the maximum likelihood estimators have the usual asymptotic properties, upon which large sample inference for the \( \beta \) parameters can be obtained. Greene (1980) proved that if the \( U_i \)'s were independent and identically distributed as \( \gamma \) random variables, with parameters \( r > 2 \) and \( \lambda > 0 \), then the required regularity conditions are satisfied.
# APPENDIX D

## SUMMARY STATISTICS

Table D.1. Summary statistics of key variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulananahela</th>
<th>Galagodabedda</th>
<th>Bibilehela–Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev</td>
<td>Mean</td>
<td>St. dev</td>
</tr>
<tr>
<td>Agricultural</td>
<td>14352.3</td>
<td>11384</td>
<td>18262.9</td>
<td>19325.8</td>
</tr>
<tr>
<td>Income (Rs/year)</td>
<td>1.126</td>
<td>0.78</td>
<td>1.16</td>
<td>0.79</td>
</tr>
<tr>
<td>Extent (acres)</td>
<td>69.72</td>
<td>30.19</td>
<td>49.92</td>
<td>36.03</td>
</tr>
<tr>
<td>Ofer (kg/year)</td>
<td>80.81</td>
<td>55.05</td>
<td>82</td>
<td>76.23</td>
</tr>
<tr>
<td>Nutrition (kcal)</td>
<td>1648.2</td>
<td>84.22</td>
<td>1600.49</td>
<td>130.85</td>
</tr>
<tr>
<td>NTFP value (Rs/year)</td>
<td>2323.99</td>
<td>3105.62</td>
<td>3291.38</td>
<td>4395.61</td>
</tr>
<tr>
<td>Fuelwood value (Rs/year)</td>
<td>5631.29</td>
<td>5448.44</td>
<td>2528</td>
<td>3539.05</td>
</tr>
<tr>
<td>Off-farm income (Rs/year)</td>
<td>10582.82</td>
<td>11130.96</td>
<td>15754.74</td>
<td>13481.47</td>
</tr>
<tr>
<td>Wealth (Rs)</td>
<td>13793.1</td>
<td>11745.99</td>
<td>11804.21</td>
<td>8767.13</td>
</tr>
<tr>
<td>Diversification index</td>
<td>2.53</td>
<td>0.74</td>
<td>2.57</td>
<td>0.76</td>
</tr>
</tbody>
</table>
## APPENDIX E

### RESULTS OF CHOW TEST

Table E.1. Comparison of regression coefficients (Chow Test).

<table>
<thead>
<tr>
<th>Forest reserve</th>
<th>Translog frontier model</th>
<th>Forest dependency model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-statistics</td>
<td>p-value</td>
</tr>
<tr>
<td>Dunhinda vs Kithulana</td>
<td>2.43</td>
<td>0.21(-03)*</td>
</tr>
<tr>
<td>Dunhinda vs Galagodabedda</td>
<td>3.28</td>
<td>0.61(-06)*</td>
</tr>
<tr>
<td>Dunhinda vs Bibilehela-Welanvita</td>
<td>3.26</td>
<td>0.71(-06)*</td>
</tr>
<tr>
<td>Kithulanahele vs Galagodabedda</td>
<td>1.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Kithulanahele vs Bibilehela-Welanvita</td>
<td>1.17</td>
<td>0.27</td>
</tr>
<tr>
<td>Galagodabedda vs Bibilehela-Welanvita</td>
<td>1.61</td>
<td>0.04*</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
APPENDIX F

VARIABILITY AMONG HOUSEHOLDS IN DIFFERENT SITES

Table F.1. Coefficient of variation in key variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulanahela</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural income</td>
<td>0.79</td>
<td>1.06</td>
<td>0.66</td>
<td>0.76</td>
</tr>
<tr>
<td>Income from animal husbandry</td>
<td>2.04</td>
<td>1.24</td>
<td>1.24</td>
<td>2.22</td>
</tr>
<tr>
<td>Off-farm income</td>
<td>1.05</td>
<td>0.86</td>
<td>1.76</td>
<td>1.14</td>
</tr>
<tr>
<td>Income from home gardening</td>
<td>1.32</td>
<td>0.58</td>
<td>0.98</td>
<td>0.15</td>
</tr>
<tr>
<td>NTFP value</td>
<td>1.34</td>
<td>1.34</td>
<td>2.25</td>
<td>2.63</td>
</tr>
<tr>
<td>Dependency ratio</td>
<td>0.7</td>
<td>1.16</td>
<td>0.82</td>
<td>1</td>
</tr>
<tr>
<td>Wealth</td>
<td>0.85</td>
<td>0.74</td>
<td>0.78</td>
<td>0.8</td>
</tr>
<tr>
<td>Diversification index</td>
<td>0.29</td>
<td>0.29</td>
<td>0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>Education</td>
<td>0.28</td>
<td>1.35</td>
<td>1.06</td>
<td>1.01</td>
</tr>
<tr>
<td>Family labor</td>
<td>0.36</td>
<td>0.39</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Distance</td>
<td>0.47</td>
<td>0.47</td>
<td>0.59</td>
<td>1.22</td>
</tr>
<tr>
<td>Experience</td>
<td>0.38</td>
<td>0.56</td>
<td>0.67</td>
<td>0.84</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>0.77</td>
<td>0.83</td>
<td>0.58</td>
<td>0.63</td>
</tr>
<tr>
<td>Efficiency index</td>
<td>0.36</td>
<td>0.34</td>
<td>0.28</td>
<td>0.32</td>
</tr>
</tbody>
</table>
APPENDIX G

RESULTS OF DEA ANALYSIS

Table G.1. Technical efficiency ranges in DEA analysis.

<table>
<thead>
<tr>
<th>Efficiency range</th>
<th>Efficiency Dunhinda</th>
<th>Kithulanchela</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TE_CRS</td>
<td>TE_VRS</td>
<td>Scale</td>
<td>TE_CRS</td>
</tr>
<tr>
<td>0-0.1</td>
<td>04</td>
<td>-</td>
<td>02</td>
<td>01</td>
</tr>
<tr>
<td>0.11-0.2</td>
<td>04</td>
<td>-</td>
<td>03</td>
<td>02</td>
</tr>
<tr>
<td>0.21-0.3</td>
<td>15</td>
<td>-</td>
<td>01</td>
<td>08</td>
</tr>
<tr>
<td>0.31-0.4</td>
<td>15</td>
<td>10</td>
<td>06</td>
<td>13</td>
</tr>
<tr>
<td>0.41-0.5</td>
<td>19</td>
<td>21</td>
<td>07</td>
<td>18</td>
</tr>
<tr>
<td>0.51-0.6</td>
<td>26</td>
<td>34</td>
<td>05</td>
<td>14</td>
</tr>
<tr>
<td>0.61-0.7</td>
<td>19</td>
<td>27</td>
<td>03</td>
<td>05</td>
</tr>
<tr>
<td>0.71-0.8</td>
<td>20</td>
<td>22</td>
<td>03</td>
<td>03</td>
</tr>
<tr>
<td>0.81-0.9</td>
<td>18</td>
<td>18</td>
<td>17</td>
<td>05</td>
</tr>
<tr>
<td>0.91-0.99</td>
<td>05</td>
<td>6</td>
<td>92</td>
<td>03</td>
</tr>
<tr>
<td>1.00</td>
<td>18</td>
<td>25</td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

112
APPENDIX H

HETEROSKEDASTICITY TEST RESULTS

Table H.1. Heteroskedasticity tests results for original model.

<table>
<thead>
<tr>
<th>Test</th>
<th>Dunhinda Chi-square</th>
<th>P-value</th>
<th>Kithulanahela Chi-square</th>
<th>P-value</th>
<th>Galagodabedda Chi-square</th>
<th>P-value</th>
<th>Bibilehila-Welanvita Chi-square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>YHAT</td>
<td>8.13</td>
<td>0.004*</td>
<td>10.79</td>
<td>0.00*</td>
<td>8.41</td>
<td>0.00*</td>
<td>4.57</td>
<td>0.03*</td>
</tr>
<tr>
<td>YHAT**</td>
<td>8.71</td>
<td>0.003*</td>
<td>14.86</td>
<td>0.00*</td>
<td>10.92</td>
<td>0.00*</td>
<td>7.72</td>
<td>0.01*</td>
</tr>
<tr>
<td>Log(YHAT**)</td>
<td>4.41</td>
<td>0.036*</td>
<td>5.17</td>
<td>0.02*</td>
<td>4.04</td>
<td>0.04*</td>
<td>1.52</td>
<td>0.22</td>
</tr>
<tr>
<td>Arch Test</td>
<td>0.077</td>
<td>0.782</td>
<td>0.29</td>
<td>0.58</td>
<td>1.67</td>
<td>0.19</td>
<td>0.13</td>
<td>0.72</td>
</tr>
<tr>
<td>Harvey Test</td>
<td>8.33</td>
<td>0.50</td>
<td>8.34</td>
<td>0.5</td>
<td>19.25</td>
<td>0.02*</td>
<td>8.71</td>
<td>0.46</td>
</tr>
<tr>
<td>Glejser Test</td>
<td>13.531</td>
<td>0.140</td>
<td>21.91</td>
<td>0.00*</td>
<td>31.27</td>
<td>0.00*</td>
<td>15.72</td>
<td>0.07</td>
</tr>
<tr>
<td>Koenker</td>
<td>13.45</td>
<td>0.143</td>
<td>15.11</td>
<td>0.09</td>
<td>8.86</td>
<td>0.45</td>
<td>7.74</td>
<td>0.56</td>
</tr>
<tr>
<td>B-P-G</td>
<td>14.328</td>
<td>0.111</td>
<td>61.26</td>
<td>0.00*</td>
<td>36.25</td>
<td>0.00*</td>
<td>61.84</td>
<td>0.00*</td>
</tr>
</tbody>
</table>

* significant at 0.05 level

Table H.2. Heteroskedasticity tests results for corrected model.

<table>
<thead>
<tr>
<th>Test</th>
<th>Dunhinda Chi-square</th>
<th>P-value</th>
<th>Kithulanahela Chi-square</th>
<th>P-value</th>
<th>Galagodabedda Chi-square</th>
<th>P-value</th>
<th>Bibilehila-Welanvita Chi-square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>YHAT</td>
<td>2.36</td>
<td>0.124</td>
<td>0.01</td>
<td>0.91</td>
<td>0.22</td>
<td>0.64</td>
<td>0.16</td>
<td>0.69</td>
</tr>
<tr>
<td>YHAT**</td>
<td>0.139</td>
<td>0.709</td>
<td>0.19</td>
<td>0.66</td>
<td>0.12</td>
<td>0.73</td>
<td>0.15</td>
<td>0.69</td>
</tr>
<tr>
<td>Log(YHAT**)</td>
<td>9.132</td>
<td>0.002*</td>
<td>0.12</td>
<td>0.72</td>
<td>0.37</td>
<td>0.54</td>
<td>0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>Arch Test</td>
<td>0.001</td>
<td>0.979</td>
<td>0.49</td>
<td>0.48</td>
<td>0.002</td>
<td>0.96</td>
<td>0.25</td>
<td>0.62</td>
</tr>
<tr>
<td>Harvey Test</td>
<td>2.867</td>
<td>0.969</td>
<td>-15.01</td>
<td>0.00</td>
<td>18.57</td>
<td>0.03*</td>
<td>9.59</td>
<td>0.38</td>
</tr>
<tr>
<td>Glejser Test</td>
<td>27.74</td>
<td>0.001*</td>
<td>-2.03</td>
<td>0.00</td>
<td>4.75</td>
<td>0.86</td>
<td>-6.55</td>
<td>0.00*</td>
</tr>
<tr>
<td>Koenker</td>
<td>31.19</td>
<td>0.000*</td>
<td>10.11</td>
<td>0.34</td>
<td>0.86</td>
<td>0.99</td>
<td>0.75</td>
<td>0.99</td>
</tr>
<tr>
<td>B-P-G</td>
<td>50.854</td>
<td>0.000*</td>
<td>11.21</td>
<td>0.26</td>
<td>5.73</td>
<td>0.77</td>
<td>2.51</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
APPENDIX I

ESTIMATION OF FOREST DEPENDENCY AS AN INCOME RATIO

Table I.1. Estimation on forest dependency as an income ratio for all forest products.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulanahela</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
</tr>
<tr>
<td>Effi</td>
<td>-0.61</td>
<td>0.07</td>
</tr>
<tr>
<td>Edu</td>
<td>0.05</td>
<td>0.67(-02)</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.44(-05)</td>
<td>0.69(-06)</td>
</tr>
<tr>
<td>Flabor</td>
<td>-0.86(-02)</td>
<td>0.73(-02)</td>
</tr>
<tr>
<td>Exp</td>
<td>-0.44(-03)</td>
<td>0.69(-03)</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.04</td>
<td>0.86(-02)</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.62(-06)</td>
<td>0.67(-06)</td>
</tr>
<tr>
<td>Dis</td>
<td>-0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>WT</td>
<td>0.93</td>
<td>0.08</td>
</tr>
<tr>
<td>R²</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>adjusted</td>
<td>(0.82)</td>
<td>(0.73)</td>
</tr>
</tbody>
</table>

* * significant at 0.05 level

OLS R² adjusted values are in parentheses

Table I.1. (Continued) Estimation on forest dependency as an income ratio for all forest products.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Galagodabedda</th>
<th>Bibichela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
</tr>
<tr>
<td>Effi</td>
<td>-0.27</td>
<td>0.07</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.23(-05)</td>
<td>0.66(-06)</td>
</tr>
<tr>
<td>Flabor</td>
<td>-0.30(-02)</td>
<td>0.69(-02)</td>
</tr>
<tr>
<td>Exp</td>
<td>0.67(-03)</td>
<td>0.60(-03)</td>
</tr>
<tr>
<td>Mfratio</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.12(-05)</td>
<td>0.11(-05)</td>
</tr>
<tr>
<td>Dis</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>WT</td>
<td>0.37</td>
<td>0.11</td>
</tr>
<tr>
<td>R² adjusted</td>
<td>0.92</td>
<td>0.96</td>
</tr>
</tbody>
</table>

* significant at 0.05 level

OLS R² adjusted values are in parentheses
Table 1.2. Estimation on forest dependency as an income ratio for NTFPs category.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulahela</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
</tr>
<tr>
<td>Effi</td>
<td>-0.09</td>
<td>0.33</td>
</tr>
<tr>
<td>Edu</td>
<td>0.55(-03)</td>
<td>0.62(-02)</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.29(-05)</td>
<td>0.32(-06)</td>
</tr>
<tr>
<td>Flabor</td>
<td>0.61(-02)</td>
<td>0.24(-02)</td>
</tr>
<tr>
<td>Exp</td>
<td>0.43(-03)</td>
<td>0.36(-03)</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.30(-03)</td>
<td>0.43(-02)</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.35(-06)</td>
<td>0.53(-06)</td>
</tr>
<tr>
<td>Dis</td>
<td>0.55(-02)</td>
<td>0.01</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>WT</td>
<td>0.36</td>
<td>0.03</td>
</tr>
<tr>
<td>R²</td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>

* significant at 0.05 level
OLS R² adjusted values are in parentheses

115
Table 1.3. Estimation on forest dependency as an income ratio for fuelwood category.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhindana</th>
<th>Kithulanahela</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated</td>
<td>Std. error</td>
</tr>
<tr>
<td></td>
<td>coefficient</td>
<td></td>
</tr>
<tr>
<td>Efii</td>
<td>-0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Edu</td>
<td>0.05</td>
<td>0.6(-02)</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.38(-05)</td>
<td>0.39(-06)</td>
</tr>
<tr>
<td>Flabor</td>
<td>0.69(-02)</td>
<td>0.39(-02)</td>
</tr>
<tr>
<td>Exp</td>
<td>0.18(-02)</td>
<td>0.65(-03)</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.66(-02)</td>
<td>0.39(-02)</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.19(-05)</td>
<td>0.77(-06)</td>
</tr>
<tr>
<td>Dis</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.11</td>
<td>0.01</td>
</tr>
<tr>
<td>WT</td>
<td>0.41</td>
<td>0.05</td>
</tr>
<tr>
<td>R^2</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>adjusted</td>
<td></td>
<td>(0.65)</td>
</tr>
</tbody>
</table>

* significant at 0.05 level
OLS R^2 adjusted values are in parentheses

Table 1.3. (Continued) Estimation on forest dependency as an income ratio for fuelwood category.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Galagodabedda</th>
<th>Bibilchela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated</td>
<td>Std. error</td>
</tr>
<tr>
<td></td>
<td>coefficient</td>
<td></td>
</tr>
<tr>
<td>Efii</td>
<td>-0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Oinc</td>
<td>-0.29(-05)</td>
<td>0.84(-06)</td>
</tr>
<tr>
<td>Flabor</td>
<td>-0.58(-02)</td>
<td>0.62(-02)</td>
</tr>
<tr>
<td>Exp</td>
<td>0.12(-02)</td>
<td>0.86(-03)</td>
</tr>
<tr>
<td>Mfratio</td>
<td>-0.28(-02)</td>
<td>0.83(-02)</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.99(-06)</td>
<td>0.12(-05)</td>
</tr>
<tr>
<td>Dis</td>
<td>0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>WT</td>
<td>0.27</td>
<td>0.11</td>
</tr>
<tr>
<td>R^2 adjusted</td>
<td>0.16</td>
<td>0.98</td>
</tr>
</tbody>
</table>

(0.53) (0.52)

* significant at 0.05 level
OLS R^2 adjusted values are in parentheses
APPENDIX J

RELATIONSHIP BETWEEN TECHNICAL EFFICIENCY AND FOREST INCOME

Regression line is $\text{FOINCOME} = *\text{EFFI} ^*$

Figure J.1. Technical efficiency vs forest income for Dunhinda forest reserve.
Regression line is $\text{FOINCME} = \text{**********} - \text{**********}\text{EFFI}$

Figure J.2. Technical efficiency vs forest income for Kithulanahela forest reserve.
Figure J.3. Technical efficiency vs forest income for Galagodabedda forest reserve.
Regression line is $\text{FOINCOME} = 5.0821 - 0.0453\cdot\text{EFFI}$

Figure J.4. Technical efficiency vs forest income for Bibilehela-Welanvita forest reserve.
Regression line is $\text{FOINCOME} = 5.0821 - 0.0453\cdot\text{EFFI}$

Figure J.5. Technical efficiency vs forest income for all forest reserves.
APPENDIX K

RELATIONSHIP BETWEEN TECHNICAL EFFICIENCY AND AGRICULTURE INCOME

Regression line is $AGINCOME = -699.94451 + 5.2989 \times 0.2163 \times \text{EFFI}$

Figure K.1. Technical efficiency vs agriculture income for Dunhinda forest reserve.
Regression line is $AGINCOME = 4581.96277 + \text{********EFFI}$

Figure K.2. Technical efficiency vs agriculture income for Kithulanahela forest reserve.
Regression line is $\text{AGINCOME} = 1344.58286 + \text{**EFl}$

Figure K.3. Technical efficiency vs agriculture income for Galagodabedda forest reserve.
Regression line is $AGINCOME = .......... + ..........EFFI$

Figure K.4. Technical efficiency vs agriculture income for Bibilehela-Welanvita forest reserve.
Regression line is $AGINCOME = -222.94246 + \text{*******Eff}$

Figure K.5. Technical efficiency vs agriculture income for all forest reserve.
APPENDIX L

RELATIONSHIP BETWEEN TECHNICAL EFFICIENCY AND HOUSEHOLD TOTAL INCOME

Regression line is TOTINCOM = 9609.92193 + ********EFFI

Figure L.1. Relationship between technical efficiency and household total income.
APPENDIX M

RELATIONSHIP BETWEEN DIVERSIFICATION AND FOREST INCOME

Regression line is $\text{FOINCOME} = \text{********* - *********DINDEX}$

![Graph showing the relationship between diversification and forest income for Dunhindia forest reserve.](image)

Figure M.1. Diversification vs forest income for Dunhindia forest reserve.
Regression line is $\text{FOINCOME} = \text{********} - \text{********DINDEX}$

Figure M.2. Diversification vs forest income for Kithulanahela forest reserve.
Regression line is $\text{FOINCOME} = 4719.52289 + *\text{DINDEX}$

Figure M.3. Diversification vs forest income for Galagod bedda forest reserve.
Regression line is $\text{FOINCOME} = \text{********} - \text{********DINDEX}$

Figure M.4. Diversification vs forest income for Bibilehela-Welanvita forest reserve.
Regression line is \[ \text{FOINCOME} = \text{**DINDEX**} \]

Figure M.5. Diversification vs forest income for all forest reserves.
APPENDIX N

RELATIONSHIP BETWEEN INCOME DIVERSIFICATION AND HOUSEHOLD TOTAL INCOME

Regression line is \( \text{TOTINCOM} = \text{**} + \text{**} \times \text{DINDEX} \)

Figure N.1. Relationship between income diversification and household total income.
## APPENDIX O

### MARGINAL EFFECTS OF PROBIT ESTIMATION

Table 0.1. Probit estimation on marginal effects on determinants of forest dependency.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dunhinda</th>
<th>Kithulansahela</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
</tr>
<tr>
<td>Effi</td>
<td>-0.71</td>
<td>0.21</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.42 (-01)</td>
<td>0.34(-01)</td>
</tr>
<tr>
<td>Oinc</td>
<td>0.39(-05)</td>
<td>0.27(-05)</td>
</tr>
<tr>
<td>Flabor</td>
<td>-0.46(-01)</td>
<td>0.18(-01)</td>
</tr>
<tr>
<td>Exp</td>
<td>-0.47(-02)</td>
<td>0.29(-02)</td>
</tr>
<tr>
<td>Mratio</td>
<td>-0.46(-01)</td>
<td>0.31(-01)</td>
</tr>
<tr>
<td>Wealth</td>
<td>0.26(-05)</td>
<td>0.24(-05)</td>
</tr>
<tr>
<td>Dis</td>
<td>-0.19</td>
<td>0.77(-01)</td>
</tr>
<tr>
<td>Dindex</td>
<td>-0.15</td>
<td>0.48(-01)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.58</td>
<td>0.24</td>
</tr>
</tbody>
</table>

n = sample size
* significant at 0.05 level

---

Table 0.1. (Continued) Probit estimation on marginal effects on determinants of forest dependency.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Galagodabedda</th>
<th>Bibilehela-Welanvita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated coefficient</td>
<td>Std. error</td>
</tr>
<tr>
<td>Effi</td>
<td>-0.67</td>
<td>0.26</td>
</tr>
<tr>
<td>Edu</td>
<td>-0.67(-01)</td>
<td>0.48(-01)</td>
</tr>
<tr>
<td>Oinc</td>
<td>0.66(-07)</td>
<td>0.22(-05)</td>
</tr>
<tr>
<td>Flabor</td>
<td>0.54(-01)</td>
<td>0.29(-01)</td>
</tr>
<tr>
<td>Exp</td>
<td>0.63(-02)</td>
<td>0.25(-02)</td>
</tr>
<tr>
<td>Mratio</td>
<td>-0.74(-01)</td>
<td>0.39(-01)</td>
</tr>
<tr>
<td>Wealth</td>
<td>-0.47(-05)</td>
<td>0.29(-05)</td>
</tr>
<tr>
<td>Dis</td>
<td>0.14(-01)</td>
<td>0.16</td>
</tr>
<tr>
<td>Dindex</td>
<td>0.66(-01)</td>
<td>0.71(-01)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.42</td>
<td>0.24</td>
</tr>
</tbody>
</table>

n = sample size
* significant at 0.05 level
REFERENCES


circle? Research report # 02, Thailand development research institute, Year-end conference, December 8-9.


Wollenberg, E. and B. Belcher. (2001). NTFPs - income for rural populations or not?

European Tropical Forest Research Network Newsletter, 32: 30-32.

development and conservation of forest products for local communities. CIFOR/
IUCN, Bogor, Indonesia.

APPENDIX A

FOREST TYPES MAP OF BADULLA DISTRICT

Figure A.1. Badulla district forest map.
APPENDIX A

FOREST TYPES MAP OF BADULLA DISTRICT

Figure A.1. Badulla district forest map.
APPENDIX A

FOREST TYPES MAP OF BADULLA DISTRICT

Figure A.1. Badulla district forest map.